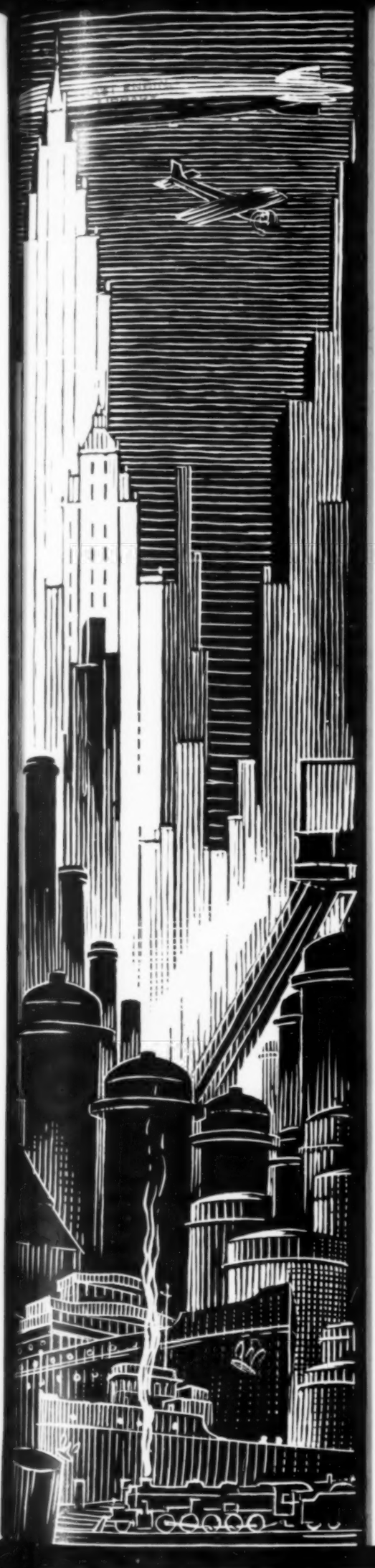

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Ernest E. Thum, Editor

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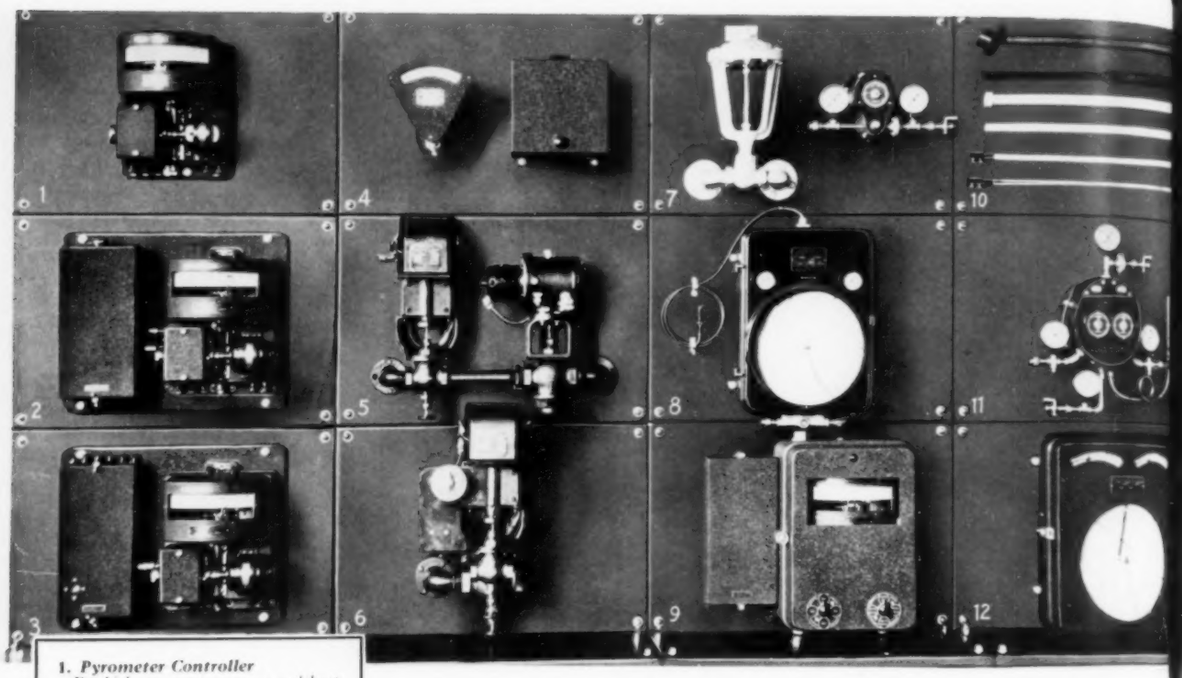

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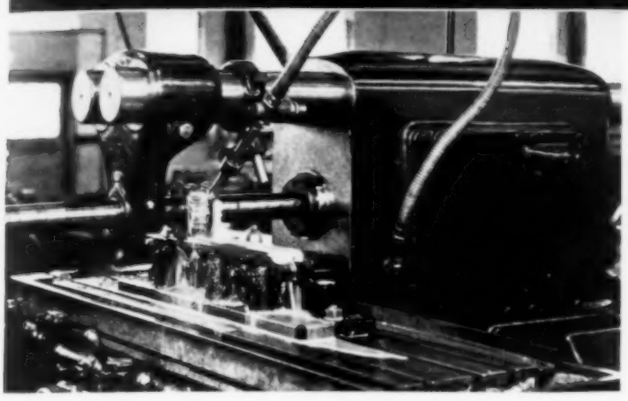

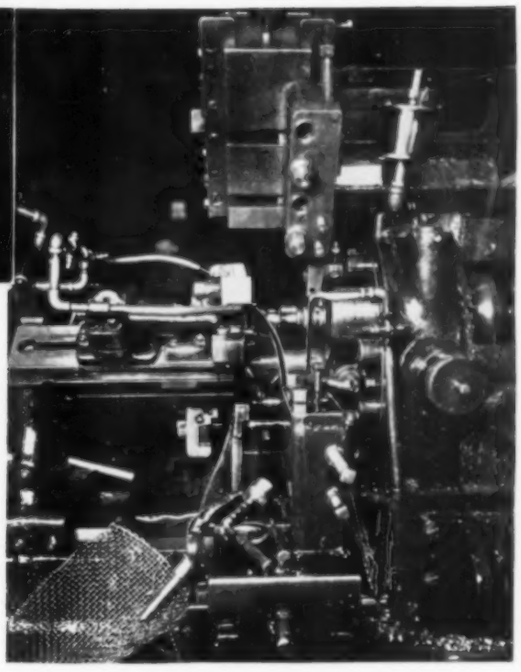

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C. E. Kraus

The Authors in this issue

The director of metallurgical research of Ontario Research Foundation at Toronto, O. W. Ellis, again is a Metal Progress author by virtue of an extended abstract of his convention paper on forgeability which begins on page 19. Mr. Ellis was born in England and received the degree of Bachelor of Science from Birmingham University there. He was later chief metallurgist for the Royal Ordnance Factories at Woolwich. His professional experience in this country includes three years as research metallurgist with Westinghouse and a fellowship at the Mellon Institute of the University of Pittsburgh. In 1917 the degree of Master of Science was awarded him by Birmingham University.

W. M. Hepburn, whose description of diffusion combustion appears on page 24, is the vice-president and chief engineer of Surface Combustion Corp., Toledo.

A test for machinability is described on page 29 by Prof. O. W. Boston, College of Engineering, University of Michigan, and C. E. Kraus, a senior in the college who is specializing in mechanical engineering. Prof. Boston, a graduate of Michigan, was assigned during the War to the Bureau of Ordnance. Later he was works manager and assistant to the vice-president of Cleveland Tractor Co. Since 1921 he has been professor of shop practice and director of the department of engineering shops at Michigan. This article is abstracted from a Buffalo convention paper.

Another paper on the Buffalo convention program will be found on page 37, where James P. Gill and H. G. Johnstin discuss testing by the deep acid etch. Mr. Gill has been metallurgist for Vanadium Alloys Steel Co. since 1920. He holds the degree of Bachelor of Science, Master of Science, and Metallurgical Engineer, having attended University of Missouri, School of Mines and Metallurgy, Rolla, Mo., and Columbia University. Mr. Johnstin graduated from University of Pittsburgh in 1926 and since then has been in the metallurgical department of Vanadium Alloys Steel Co.

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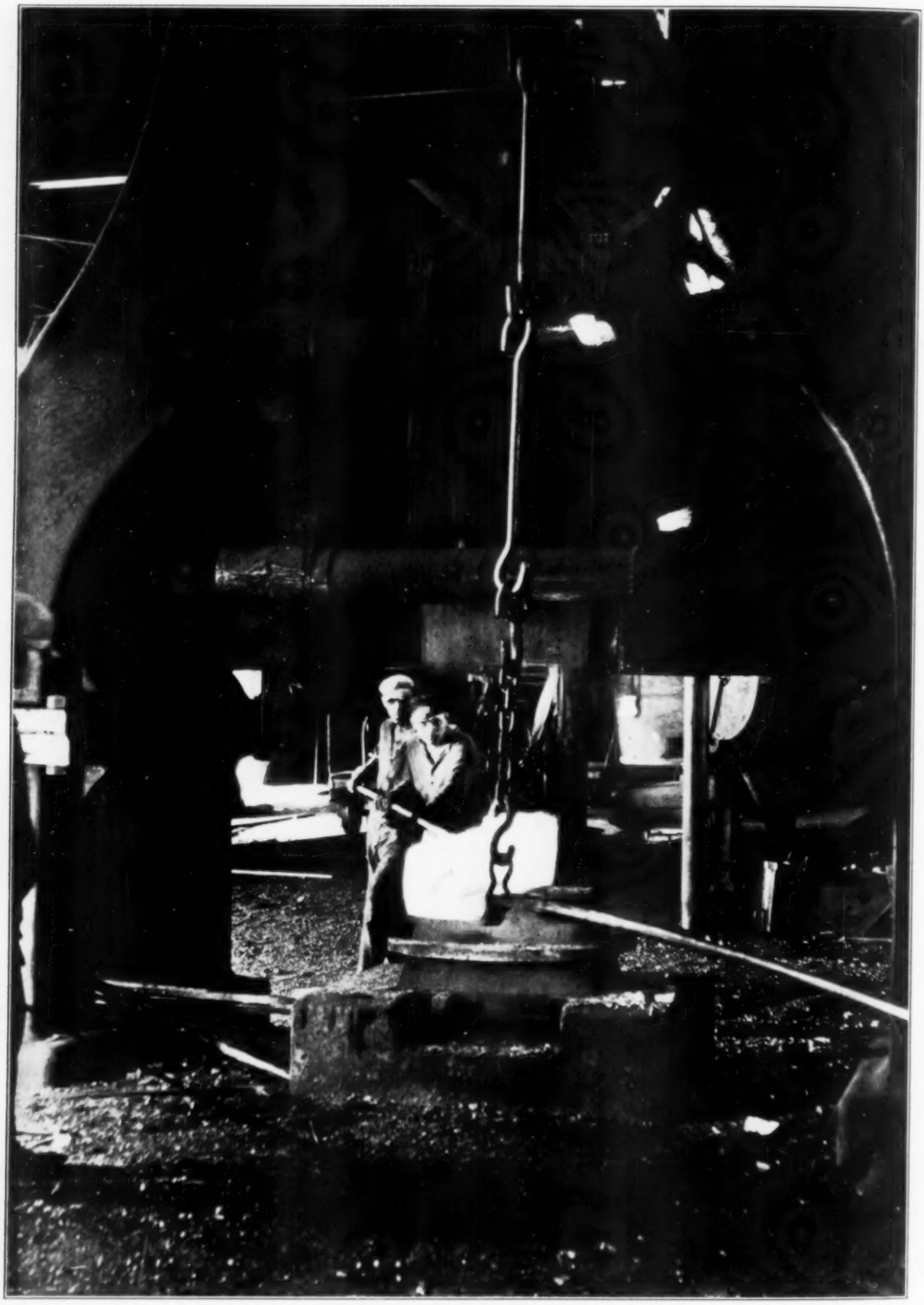


Photograph by Margaret Bourke-White for Ludlum Steel Co.

By O. W. Ellis
Director of Metallurgical Research
Ontario Research Foundation

Forgeability of steel

as influenced by composition and manufacture

Abstract of a paper for Buffalo Convention, A.S.S.T., October, 1932

IT IS NOW twenty-two years since Robin investigated the resistance of steels to crushing (Carnegie Scholarship Memoirs, British Iron & Steel Institute, 1910). This work has never received the attention it merits; certain of his observations, had they been applied in practice, would unquestionably have eliminated the useless expenditure of a large amount of energy in both smithy and forge shop.

Robin, among other things, estimated the amount of energy required to reduce normal cylinders (cylinders whose heights and diameters are equal) by 20% of their original height. The effects of the critical ranges of steels upon their resistance to crushing were not considered by Robin, but in 1924 and 1926 Ellis published in the same Memoirs investigations which showed clearly that the critical ranges had a very important effect.

At the same time the present writer determined the relationship between the energies of the blows applied to normal samples of a series of straight carbon steels at a given temperature and the amount by which they were deformed. For each of the steels he examined he obtained families of curves, such as are shown in the figure on the next page. He confirmed Robin's general findings that carbon tended to increase the resistance of steel to plastic deformation at any given temperature.

It is obvious that the size of specimen must be taken into account. Robin emphasized the value of Tresca's theorem that for a given steel the energy required to deform similar shaped bodies a certain percentage will vary as the volumes of the bodies concerned. This law has been verified in comparing the results of the two Carnegie Memoirs above cited. Such close agreement would indicate that the methods used for determining the forgeability of carbon steels at various temperatures are generally satisfactory. Furthermore, they may be correlated with the results of work now to be described on samples 1 in. in diameter and 1 in. high, struck with a single blow of 520 ft-lb. In the course of these studies the forgeability of some common alloy steels, and the forgeability of a steel of constant analysis as affected by pronounced variations in melting practice, were investigated.

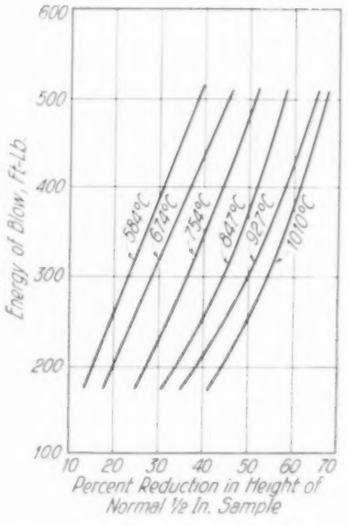
The apparatus used in these tests is shown in the half tone on page 21.

Samples were heated in a Globar furnace, controlled by a Bristol pyrometer controller. When a desired constant temperature had been reached, three samples were placed close to the hot junction of the controlling pyrometer. One of these samples had been drilled and contained the hot junction of another pyrometer, snugly fitted, so that the temperature of the center of this sample was known.

When its temperature had remained constant for 5 min., one of the other samples was placed on the anvil of the drop-hammer, and

the tup dropped. The sample was allowed to remain under the tup until cool. The other undrilled sample was quenched in water at 20° C. to confirm the position of the critical range as determined by the forging experiments. It was assumed, and was found to be true, that a marked increase in hardness would coincide with the somewhat radical change in the forgeability - temperature relationship for the various steels being investigated.

After the forged sample had cooled, its height was measured and the percentage reduction computed.



Reduction of Height of Slug ½ In. Diameter by a Single Blow at Temperatures Noted

Using 1-in. normal samples, tests were conducted on a series of straight carbon steels of 0.10, 0.16, 0.68, and 0.85% carbon respectively. Results of these tests are shown in the figure opposite. It indicates how clearly the critical points are brought out.

It is scarcely necessary to discuss the curves in detail. The fact that carbon has a profound effect upon malleability is quite clearly indicated. One point of interest may be referred to —namely, that at temperatures below the critical range the 0.68% steel is far less malleable than the 0.85% carbon steel. The latter was doubtless annealed (Brinell 175); the other was in the "as rolled" condition when received and as tested (Brinell 205). Had the lower carbon steel been annealed prior to test, its curve at temperatures below the critical range would have lain between the curves for the 0.16 and 0.85% carbon steels rather than below the last mentioned.

Effect of Alloying Elements

A series of alloy steels, in 1-in. round rods, was purchased from stock and tested as received. Effects of structure upon their forgeability at temperatures below the critical need scarcely be considered; normally, of course, forging of steels takes place above the critical range.

An S.A.E. 2320 steel was used to study the effect of nickel upon the forgeability of steel having a relatively low carbon content. The steel contained 0.20% carbon, 3.51% nickel, and no chromium, vanadium, or molybdenum.

The forgeability-temperature relationship is shown in the lower figure on page 22. It will be noted that the A_1 point and the A_3 point are clearly shown.

The forgeability of the 0.16% carbon steel is shown on the same diagram in solid line. It will be clear that such difference as does exist in forgeability of these steels at, say, 900° C., can be accounted for entirely by the somewhat greater carbon content of the nickel steel. To sum up, one may say with some confidence that the presence of 3.51% of nickel has but little effect, if any at all, upon the forgeability of low carbon steel under the conditions of these experiments.

Turning now to the effect of altering the carbon content of a nickel steel containing approximately 3.5% nickel, an examination was made of an S.A.E. 2345 steel. It contained 0.41% carbon, 3.38% nickel, and no chromium, vanadium, or molybdenum.

Forgeability of this steel and a comparison curve for the 0.68% carbon steel are shown in the same figure as mentioned above. The relative importance of carbon and of nickel in raising the resistance of steel to plastic deformation at temperatures above the critical ranges can be judged. From this it appears that the addition of nickel to medium carbon steel has the effect of increasing its resistance to forging, particularly at temperatures above 1000° C. or thereabouts.

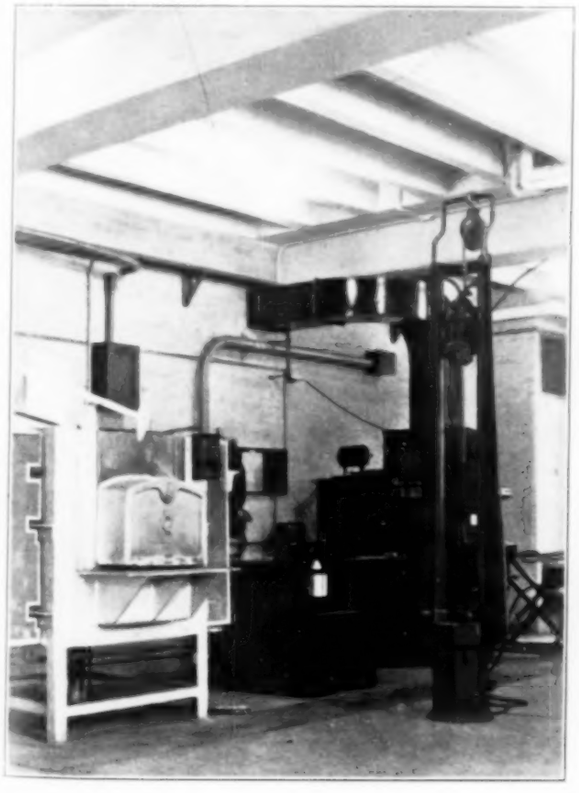
For the purpose of investigating the effect of chromium upon the forgeability of steel, material approximating S.A.E. 5130 was employed, marked steel J in the figure on page 23. It contained 0.28% carbon and 0.83% chromium, no nickel, vanadium, or molybdenum.

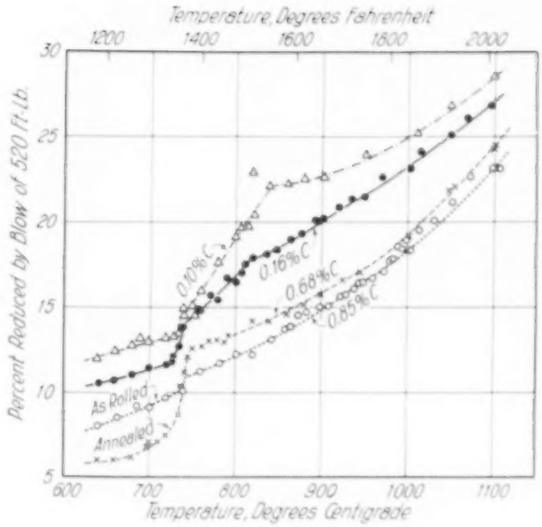
A comparison of its forgeability with that of the carbon steels shows it to lie between the

curves for the 0.16 and the 0.68% carbon steels and actually to intersect the curve for the latter at about 1100° C. One is led at first to believe that chromium must have a relatively profound effect upon forgeability, even though no direct comparison was made between steels having approximately the same carbon content. However, since the malleability of low carbon steels appears to be reduced by carbon far more rapidly than the malleability of high carbon steels, the low forgeability of this chromium steel relative to the 0.16% straight carbon steel may be due to the difference in carbon rather than to the chromium content of the former.

A series of steels containing nickel and chromium was investigated. Steel E falls in line with the specification for S.A.E. steel 3120, steel A with the specification for S.A.E. steel 3135, steels C and K with the specification for S.A.E. steel 3245. Analyses are given on curves at the top of the next page. It will be noted that steels C and K are practically identical in analysis, and were tested completely to determine to what extent results might be reproduced.

Furnace and Drop Hammer Used in Forgeability Tests



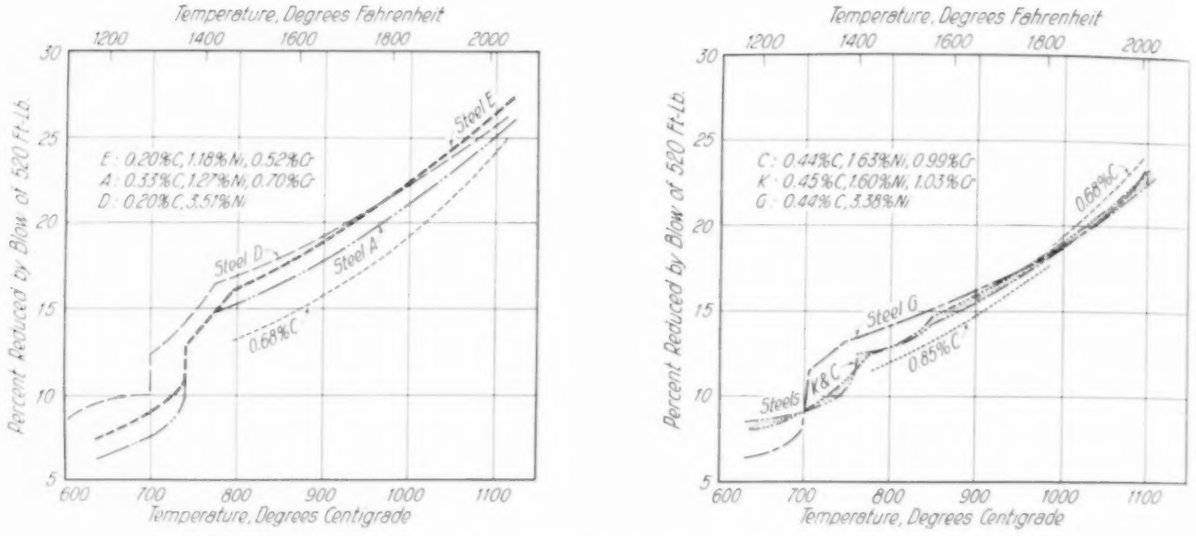


Forgeability - Temperature Relationships of Four Carbon Steels Tested Under Similar Conditions

The curves at the top and left compare the effects of nickel and of nickel plus chromium upon the forgeability of steels of approximately the same carbon content. Steels E and D, which have the same carbon content, but which differ quite appreciably in their alloy contents, are close to one another at temperatures above A. On the other hand, steel A, which contains more carbon than either of the others, is distinctly more resistant to deformation. If the curve for the plain chromium steel described above were plotted it would be slightly below the curve for steel A. One is led again to the view that carbon is far more potent in its effect upon the forgeability of *low* carbon steel than are either nickel or chromium, or these two elements combined.

Areas between the curves for steels C and K have been darkened so as to indicate clearly the slight differences between results on two steels of practically identical composition. It will also be observed that the curve of a steel which contained the same carbon and 3.38% nickel is nearly the same at temperatures above about 850° C. Differences below 850 are due, in all probability, solely to the difference in the positions of the upper critical points.

Portions of the curves for the 0.68 and 0.85% carbon steels are also sketched in. One would judge from this comparison that the addition of about 1.6% nickel and about 1% chro-

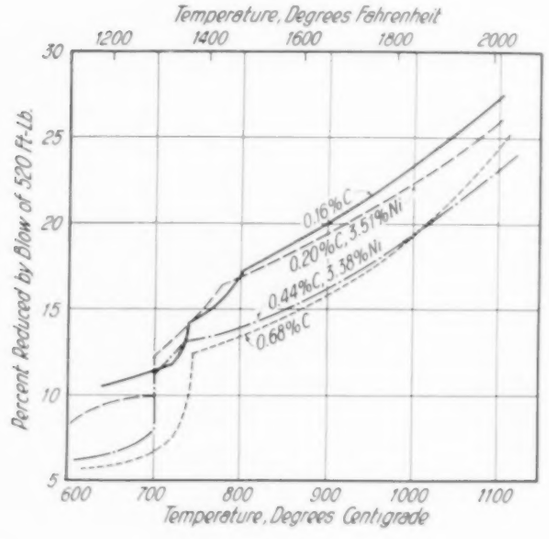


Relative Effects of Nickel and Chromium on Malleability of Common Alloy Steels

mium to a carbon steel having about 0.45% carbon decreases its malleability, this decrease being slightly greater at high temperatures than at low (on assumption that the forgeability-temperature curve for a 0.45% straight carbon steel would lie above the curve for the 0.68% carbon steel).

For the purpose of determining what effect vanadium had upon the forgeability of S.A.E. 5130, the chromium steel J described above was compared with one having 0.14% vanadium (figure on the opposite page). The curves demonstrate their similarity above the critical range. One might be tempted to suggest that vanadium alters the rate of change of forgeability with temperature, in view of the difference in slope of the two curves, but would hesitate, having seen the variations that can be obtained from two nickel steels of practically the same analysis. The very marked difference in malleability at temperatures below the critical range can unquestionably be considered as due to the vanadium. In the "as received" condition, steel I was Brinell 260, and steel J was 140, and the former was invariably harder after normalizing at a series of temperatures from 800 to 1092° C.

Nickel Decreases Forgeability of Medium Carbon Steels, but Has Little Effect on Low Carbon Steels



It appears from the foregoing results that the addition of nickel, of chromium, or of nickel plus chromium to low carbon steel has but little effect upon its forgeability, whereas the addition of these elements to medium carbon steel has the effect of reducing their forgeability, possibly of reducing it more noticeably at high than at low temperatures.

Influence of Melting Practice

A series of 0.90 C steels was supplied by Dr. H. B. Allen, chief metallurgist of Henry Disston & Sons, Inc. Two contained about 0.07% of both nickel and chromium; one bar was from an electric furnace heat and one from an open-hearth heat. The other three had

slightly more chromium, 0.67% nickel, and 0.14% molybdenum; of these one was made in the open hearth, another in the electric furnace of a charge containing 40% sponge iron, and the last in the same manner except that the charge contained 13% sponge iron.

Tests on these five steels fall within the hatched area in the figure. The forgeability-temperature relationships are practically identical. It can scarcely be assumed that either the method of manufacture or the presence of sponge iron in the charge was effective in producing the slight differences which were observed in the results of the tests.

Method for Determining Energy

The author feels that one of the most important developments of this work has been a simple equation covering families of such curves as shown in the first figure.

If E be the energy in foot-pounds required to produce a certain definite percentage reduction in height D of a normal sample ½ in. diameter by ½ in. high, then E and D are related by the following equation:

$$\log E = \log b + (1.56 - 0.47 \log b) \log D$$

where b is a parameter which can be found by making one drop test on the steel being investigated at the temperature in question.

Some discrepancies occur between observed and calculated values, but a study of a very large number of tests has resulted in the equation shown.

To illustrate the accuracy of the equation, take the following:

A ½-in. normal sample of 0.08 C steel was reduced 44.0% in height by one blow of 169.5 ft-lb. By calculation, the energy required to reduce this sample 71.0% (at the same temperature) was found to be 497.7 ft-lb. By experiment: 508.5 ft-lb. (In this calculation the logarithms of 44% and 71% are taken rather than the logarithms of 0.44 and 0.71.)

In order that the equation may be applied to normal samples of all sizes, it is necessary to bear in mind Tresca's theorem, stated above, and which may be expressed mathematically as follows: $E_1 : E = V_1 : V$.

It is apparent that the factor 2^3 or 8 would be necessary to make the above equation applicable to the 1-in. normal samples used in the recent work described herein. The equation then becomes

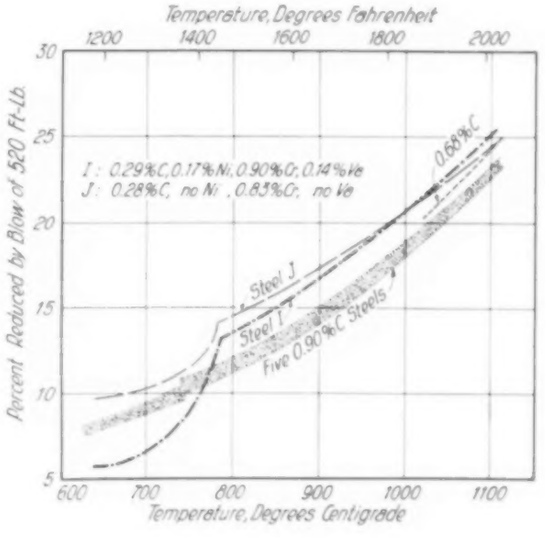
$$\log E_1 = \log 8 + \log b + (1.56 - 0.47 \log b) \log D$$

By means of this last equation an estimate, for example, can be made of the energy required to reduce the 0.16% carbon steel by 40% in height under a single blow at a temperature of 950° C. Reference to the diagram on the opposite page will show that this steel is reduced by 21.5% in height at that heat under a blow of 520 ft-lb. By using the second equation one arrives at the conclusion that 1690 ft-lb. of energy would be required.

Knowing the amount of energy required to reduce a 1-in. normal sample of steel by, say, 40% in height, the Tresca relationship can be applied to estimate the energy required to reduce the height of normal samples of the same analysis of steel of other dimensions by the same amount.

It is fully recognized that before accurate determinations can be made of the energy required to effect specific changes of shape in samples of varying dimensions, far more work than has been presented here must be done. It is believed, however, that the method described does offer a rough and ready means for obtaining a very much closer idea than has hitherto been possible.

Chromium Seems to Harden Steel at Forging Temperatures, but Vanadium Has Little Effect. Neither has method of manufacture on forgeability of high carbon steel



By W. M. Hepburn
Chief Engineer
Surface Combustion Corp.
Toledo, Ohio

Diffusion Combustion

new application of old principles

RUMORS about remarkable performances of furnaces heated with so-called "diffusion combustion" flames have been spreading throughout the metallurgical industry. Little definite information has been broadcast, for important commercial developments have been undergoing a period of careful observation in a number of industries. Within the last year large continuous glass "tanks" (furnaces wherein the raw materials are melted) have been doubled in production without any apparent decrease in life, the quality of the glass improved, and the fuel consumption reduced. While developments are still far from complete, the results so far secured in practice and the findings of laboratory and theoretical studies warrant us in believing that equally noteworthy advances may be made in the heating of metals.

It will be well at the very outset to define "diffusion combustion" and particularly distinguish it from "luminous combustion."

In diffusion combustion the chemical reactions producing the flame occur only by the interdiffusion of oxygen from a stream of air into a parallel stream of the gas from the burner. Such combustion is confined to a very thin surface, called the "flame front." A simple and homely example is the lower part of a gas light or candle flame.

A diffusion burner can be made of two concentric pipes; through the inner is blown gas, through the outer pipe air at the same velocity. This produces a moving cylinder of air having a core of gas; combustion will proceed only as the two mix. If the moving cylinders of gas are protected from anything to cause turbulence, the action will produce a long pencil of flame. The surface of this flame is very thin; within it is a moving column of gas; without it is a moving column of air.

Theoretically, it is possible for these flames to be 242 ft. long. Actually, our engineers have projected them 84 ft. To attempt a greater distance in a laboratory involves an expense not yet justified in this development work.

Diffusion flames are clearly quite different from most of those now used by industry, wherein part or all of the air necessary is mixed with the gas inside the burner, and combustion occurs almost simultaneously in large volumes of the mixture. The latter type of flames has been called "Bunsen flames," from the analogy to the familiar laboratory gas burner.

It should also be obvious that diffusion combustion, being a type of action, has no relationship with luminosity. Elementary physics teaches us that at ordinary flame temperatures it is incandescent solid particles of carbon which throw forth the light. If a gas rich in hydrogen and low in the heavier hydrocarbons is burned in a diffusion burner, it produces all the heat units contained in the gas, yet the flame gives so little light that the workmen are entirely incapable of judging operations by eye. "Cold flame," they call it.

On the other hand, a diffusion flame can be intensely luminous if the fuel gas contains a considerable quantity of unsaturated hydrocarbon gas, either naturally or by pre-mixture. This apparent paradox arises because the conditions within the core of unburned gas are proper for the maximum precipitation of carbon. In fact, the research work on the entire problem was originally undertaken for the more efficient production of commercial lampblack from natural gas.

Its possibilities for use in furnace work were recognized by our own research department, and immediately their activities were coordinated with the Combustion Utilities Research Organization of Linden, N. J. S. P. Burke and T. E. W. Schumann of the latter organization worked out the mathematical and physical theory, and published a scientific paper on this matter in *Journal* of Industrial & Engineering Chemistry in October, 1928.

Theory, experiment, and practice indicate that the height (or length) of the flame is proportional to the velocity of air and gas but is independent of the pressure or preheat (if both gas and air are preheated uniformly). It might be thought that the high temperature caused by the thin sheath of flame would rapidly expand the gas and air and thus produce turbulent flow, but the added temperature merely increases the rate of diffusion of the hot air into the hot gas and vice versa. The height of the flame is not affected by the area of the gas and air ports if the flow is kept constant. However, if the flame is "overventilated" it will pinch out in a dagger shape at the axis. If "underventilated" the flame front (or surface where burning takes place) flares out in a bell shape. Typical flame shapes for underventilated and overventilated flames from a 2-in. burner are shown in the diagram, taken from Messrs. Burke & Schumann's paper noted above.

These theoretical flame shapes have been verified abundantly in actual experiments; they are characteristic enough to enable the operator to regulate the gas and air supply so the flame fills the entire furnace.

The above principles are responsible for the four main distinctions between diffusion combustion and the previous methods of luminous combustion.

1. Diffusion combustion holds practically a constant rate of radiation for its designed length of travel. In other words, its emissivity is constant. Combustion is at a constant rate, and the carbon precipitation is uniform.

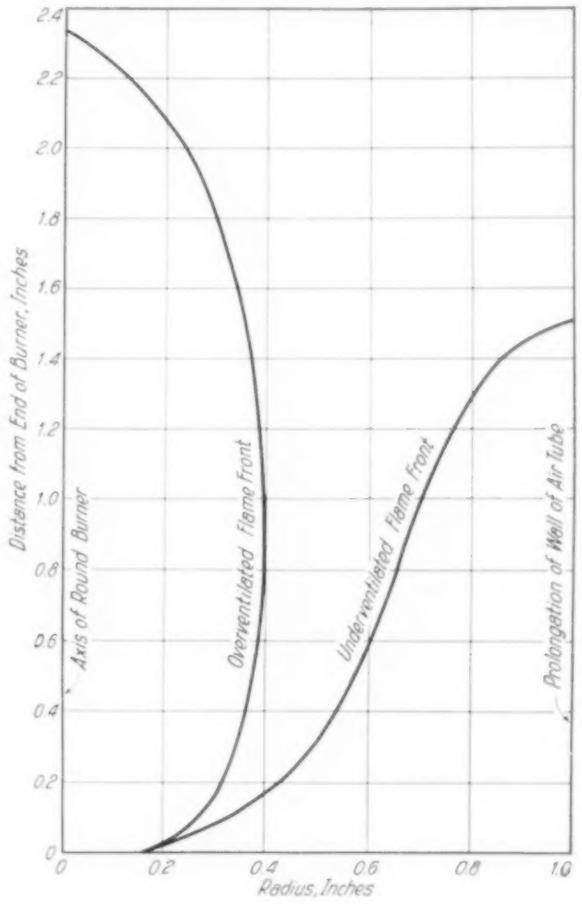
2. The flame contains the greatest amount of free carbon possible with combustion, and the streamline flow of the gas and air strata insures constant conditions.

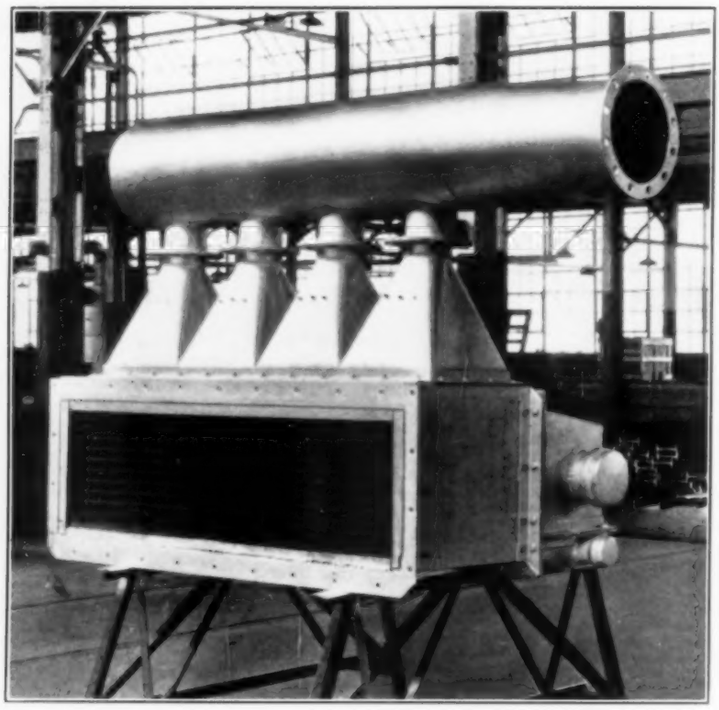
3. Diffusion combustion preserves a constant flame temperature for its designed length of travel.

4. A protective layer of sooty gas can be maintained constantly over the work being heated, thus effectually excluding oxygen and nitrogen of the air.

The practical value of these four distinctions will be in an increased rate of heating over the rate afforded by luminous combustion.

Theoretical Shape of Slightly Underventilated and Slightly Overventilated Flames From Burner Made of Pipe 2 In. Inside Diameter, According to Burke and Schumann





Diffusion Combustion Burner for Large Metallurgical Furnace. Note extra row of close-packed ports at bottom to blanket the steel with protecting gas

a lower furnace temperature with correspondingly decreased maintenance cost, a more accurate control over unavoidable variations by the automatic temperature devices, and a better surface condition on the materials heated.

Even with all these advantages it is a mistake to appraise this development exclusively in terms of increased fuel economy over an efficient type of non-luminous combustion.

The figure above shows a very large diffusion burner for a metallurgical furnace. Gas enters from a box at the rear through a multitude of small burner ports. Air comes down from above and is deflected outward, passing the ends of the ports with the same velocity as the gas is leaving. An extra row of close-packed ports at the bottom eject enough gas to blanket the work on the hearth and protect it completely.

A typical example of a diffusion combustion slot forge furnace is shown on page 27 in which the gas blanket is utilized to produce the absolutely scale-free work required by modern press forging practice. The furnace has a heating capacity of 1700 lb. per hr. and when heating steel to 2350° F. at this rate (148 lb. steel per sq.ft. of hearth per hr.) has a fuel consumption of about 4.4 cu.ft. of 530-B.t.u. gas per lb. of steel. The somewhat higher fuel consumption over that required by the modern continuous furnace is due not only to the type of furnace (continuous furnaces being generally more efficient than batch-type furnaces) but also to the use of the gas blanket for protecting the work.

In such applications the lower stratum, or that in contact with the work, is of raw gas, and this gas blanket is maintained unbroken throughout the length of the furnace because of the streamline, non-turbulent or laminar flow of the gases from the burner. The work being heated is immersed in this inert stratum during the entire time it is in the furnace.

Diffusion burners can be set into the rear walls of smaller box-type furnaces for heating small steel and alloy billets to 1900 to 2300° F. for miscellaneous forging. In such installations it is impossible to utilize a gas blanket, but the beneficial action of the free carbon in the flame is such that the scale is much less troublesome than after other methods of heating. Diffusion combustion burners have also been installed on continuous furnaces for heating bars for forging automobile axles. Again, in this case, the protective gas blanket is not used but the scale formed on the work is thin and of a type which does the least harm to the forging dies.

Die and Material Costs Cut

On the basis of extensive tests one large producer of forgings estimated that the use of diffusion combustion would result in a saving of 10% in die expense and a 1% saving in steel.

Most of the applications so far have been to high temperature operations, but even for operations such as annealing, normalizing, and hardening, diffusion combustion has been applied with good results. A halftone on page 28 shows a continuous furnace unit for normal-

izing and hardening automobile axles in which diffusion combustion burners operate in conjunction with Surface Combustion non-luminous flame burners. Formerly, when operating only with the non-luminous flame burners the work had a tight scale which required a long pickling period. With the addition of the new burners, the effect of the free carbon in the furnace atmosphere is such that the scale on the work is light and loose and is almost entirely removed in the quench. The metal's surface is in excellent condition for further work on the piece. To secure the same results with a non-luminous flame the furnace atmosphere would have to contain 6% CO, which in turn would require 30% excess gas at the burners. This would mean an excessive fuel combustion and an industrial hazard as well.

This naturally brings up the question,

"Why would free carbon have any greater benefit in a furnace atmosphere than merely a certain excess of unburned gas?"

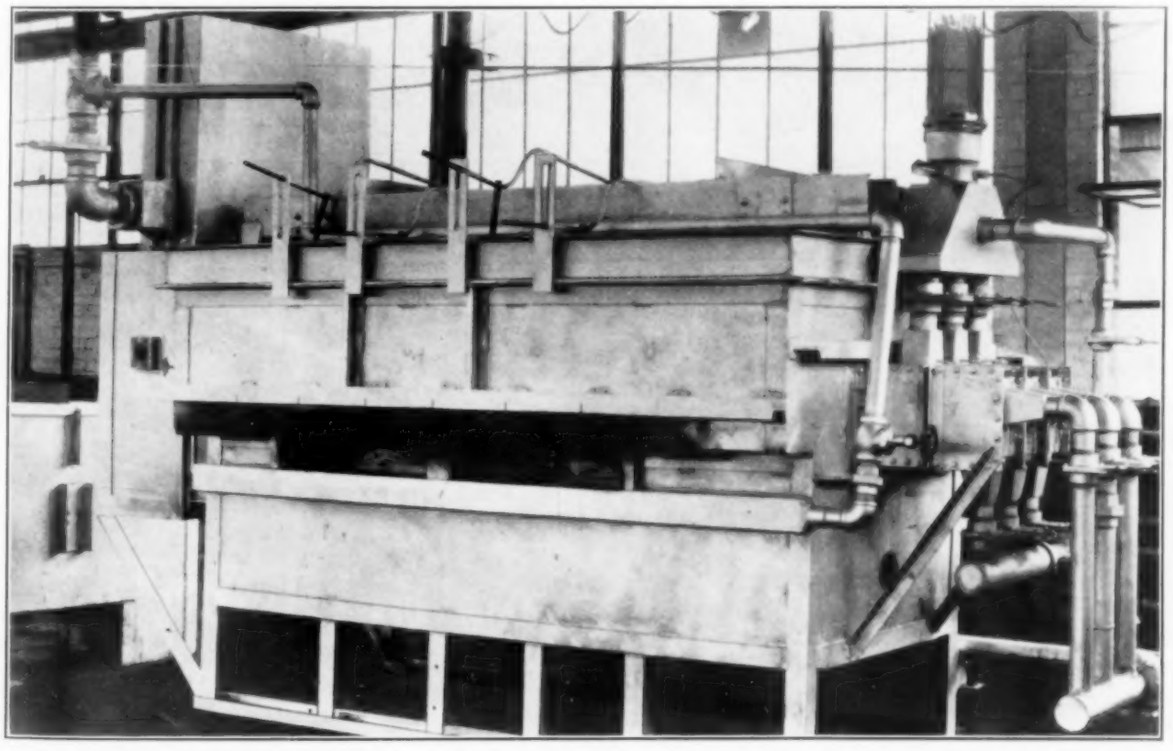
This is rather difficult to answer logically and rigorously, but it is an experimental fact that free carbon on a hot metal surface in the presence of flue gas has quite a different effect on the metal surface than if the latter were exposed to excess CO in the presence of flue gas. The carbon is unusually active, as though it were in a nascent state. In other words, at the instant the chemical reaction occurs between carbon and oxygen, the reducing effect of the carbon is greatly accelerated.

Effect of Free Carbon

Free carbon in a furnace atmosphere offsets the oxidizing condition of a certain amount of air infiltration which otherwise would have caused troublesome scaling in a non-luminous type of furnace. In the case of a car-bottom annealing furnace, the decarburizing effect of the flue gases is neutralized by injecting a certain amount of free carbon into the furnace. In another plant, using a wire normalizing furnace to heat the coiled wire to around 1900° F., free carbon has prevented detrimental scaling of the outer coils of the wire.

I cannot overemphasize the importance and value that this control of free carbon has given us on the furnace atmosphere in handling steel at elevated temperatures.

Slot Furnaces May Heat 3-In. Forging Billets Without Any Scale



Despite these remarkable achievements diffusion combustion is not a cure-all; it cannot be applied to all furnaces. Up to this time, its scope has been limited, since each job has been given thorough engineering analysis.

Diffusion Burners of All Types

Since we can grade off into a great variety of burners from the true diffusion type down to the conventional type of luminous burners, we can begin to appreciate the reason why it is not possible to set forth one elementary explanation of this new development.

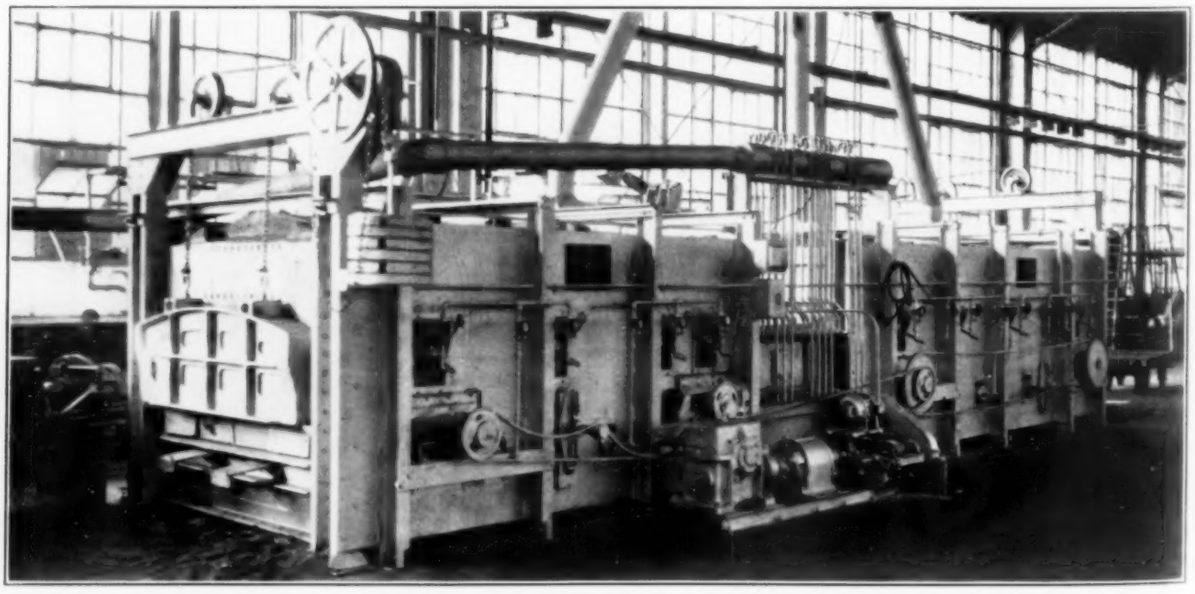
It is not true that luminous combustion heats faster than non-luminous. The fastest commercial heating which I know about uses natural gas and non-luminous combustion. The flame is made to impinge directly on the bath of a copper smelting reverberatory furnace. Gas and air are mixed in such proportions that the hot zone of this flame will occur directly on the bath's surface. Bear in mind that to make a flame luminous, we must violate some very good combustion principles, and if you do not offset these violations by something more than mere luminosity, you will have nothing more than we have had for the last three hundred years. In diffusion combustion we have substituted for mere thermal efficiency the four practical advantages mentioned above, which are of overpowering value.

The essential action of a hot flame with incandescent carbon particles is a problem in advanced thermodynamics. About all we can say in general is that gases at a certain temperature will transfer heat at a faster rate if free carbon is present than if the gases are non-luminous. There is a certain amount of radiation from non-luminous gases for any given temperature, but the addition of free carbon will speed up this rate of heat transfer by radiation.

What is Luminosity?

Luminosity is not a quantity, but an optical observation. Ordinary variations in the amount of carbon in the flame cannot be detected by eye. However, this carbon does increase the amount of energy radiated at low wave lengths, and this is easiest absorbed by the metal being heated. Carbon liberated in the flames is very, very fine, and a number of layers of it are necessary. Hence the construction of burners with a very large number of gas ports or jets. Each of these flames acts as a unit in liberating free carbon, but all together make a correspondingly dense cloud of solid particles which transform a very high percentage of the energy of combustion into radiant heat.

Partial Diffusion Combustion Produces Enough Free Carbon in Furnace Atmosphere to Control Amount and Adherence of Scale When Normalizing or Hardening Alloy Steel Parts



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University of Michigan

Machinability measured by simple tool

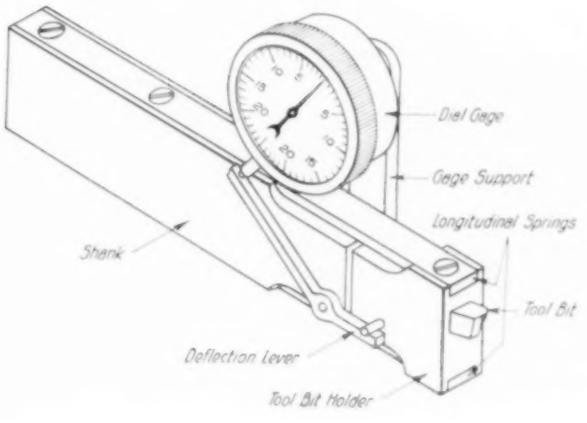
Abstract of a paper for Buffalo Convention, A.S.S.T., October, 1932

OF THE MANY methods of measuring machinability, one giving tool life has most practical value. Tool life tests are, however, difficult and expensive to obtain. Other types of tests have been used, such as the torque, thrust, and power developed in drilling, or the force on a planer or lathe tool as measured by a dynamometer. These methods all have certain objections in that the results, as in the case of drill penetration, do not always indicate the most favorable machining conditions, or in that the devices are expensive, difficult to operate except by trained personnel, and the tests require considerable time before results are obtained.

The device to be described is intended primarily for comparative tests of a routine nature, such as for example, the testing of various specimens of steel screw stock for uniformity and ease of cutting. It is illustrated by the line diagram, and is designed to fit into an ordinary tool post of a lathe, planer, or shaper. The tool consists principally of a shank — a bit holder, machined as a single piece and then cut in two — and a deflection indicating mechanism. Set into a longitudinal groove flush with the top surface and separating the tool holder slightly from the shank are two steel springs. These permit a vertical motion of the bit holder perpendicular to the longitudinal axis of the shank, and this is transmitted to the dial indicator fastened to the shank.

In order to make the device as rugged as possible, the springs were made quite heavy and the lever was designed to amplify the deflections of the tool point. The holder takes a $\frac{1}{4}$-in. square tool bit which, as in ordinary tool holders, is held at a 15° back-rake angle.

A calibration curve of the holder, showing the relation of the dial gage reading to the load on the tool, is approximately a straight line and should be drawn by appropriate experiments on each tool holder. The calibration of our holder was carried out while the tool point projected $\frac{9}{32}$ in. beyond the end of the holder, but since the device is essentially a parallel linkage, the projection of the tool bit has practically no effect on the calibration curve. By modifying the tool springs and the lever ratio, any moderate range of tool pressures could be measured.



In order to demonstrate the usefulness, adaptability, and limitations of this conveniently applied tool, the results of a number of different tests will be presented.

Tests were first run to ascertain the best range of feeds and depths of cut for subsequent work. A bar of low carbon cold rolled steel taken from stock was centered and trued up, after which it measured 2.5 in. in diameter. It was run at 98 r.p.m. which gave an initial surface cutting speed of 64 ft. per min.

The high speed tool bit was ¼ in. square section, ground so as to have no side-rake angle, a 15° back-rake angle, a 6° end-cutting angle, a 6° front and side-clearance angle, a setting angle of 90° (that is, the axis of the tool and the cutting edge were at right angles to the axis of the work), and a 0.010-in. nose radius. Bits of this particular size and shape are designated as "A."

For each depth of cut of 0.010, 0.020, 0.025, and 0.030 in., feeds of 0.004, 0.0069, and 0.0091 in. were used. Two identical series of tests were run, the results of which are shown plotted as tangential cutting force in pounds over the variable on log-log paper in the figure. The two series of tests compare favorably with one another. Even greater depths of cut and feeds might have been taken. The surface of the metal cut was very smooth and showed sharply defined and unbroken feed helix lines. Vibration of the dial indicator needle was not objectionable. (Later tests on a steel-mix casting gave considerable vibration of the gage needle and accurate reading was difficult.)

These results indicate that the tool pressure is an exponential function of the feed and depth:

$$P = 38{,}700\ F^{0.67}\ D^{0.94}$$

in which P is the tangential cutting force in pounds, F is the feed, and D is the depth of cut in inches. It is apparent that, for the range of feed and depths of cut covered by this equation, metal can be removed much more efficiently with coarse feeds than with fine feeds and that the depth of cut has very little effect on the efficiency.

Similar tests were repeated in triplicate on an annealed S.A.E. 3150 steel which had been used in a number of other machinability tests.

Succeeding Tests in Agreement

The "B" tool was used in tests in which the back and side rake of tool "A" was changed to 8° and 14°, respectively, as these angles had been used more often in other tests. Again, a close agreement in corresponding values is noted and is found to be

$$P = 155{,}000\ F^{0.78}\ D^{0.94}$$

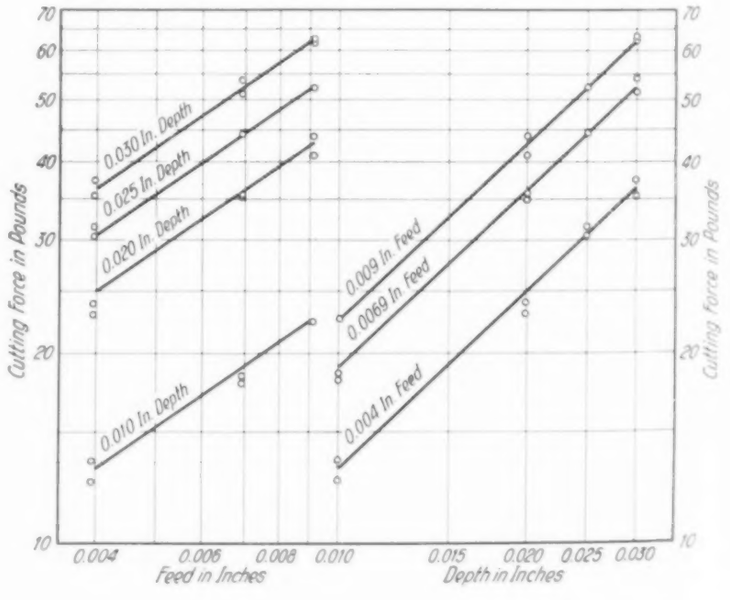
This equation is shown to agree very well with that obtained in planer tests made previously on the same steel by more tedious methods as follows:

$$P = 128{,}200\ F^{0.78}\ D^{0.93}$$

Difference in the exponent of feed F in these two equations from the one given two or three paragraphs above is due probably to the fact that tool "A" was used in one case and tool "B" in the other.

The constant or coefficient of the equation for pressure on the turning tool is 21% higher than that of the planer dynamometer. The reason for this cannot be explained. It may be due to the fact that a slightly higher cutting speed was used in turning than in planing, or that there is a difference in the constant due to straight line cutting over turning. Check

Cutting Force for Light Cuts on Low Carbon Cold Rolled Steel



tests were run with a feed of 0.007 in. and a depth of cut of 0.025 in. with the tool used in the turning tests and with a tool ground and honed to the exact shape and condition of that used in the planer tests, and only a 3% greater force in turning was found. (The tool used in the planer tests was honed all over and had a $\frac{1}{32}$-in. radius as compared to the unhoned tool used in turning with a 0.010-in. nose radius.)

Taylor's formula when cutting steel was

$$P = 230{,}000\ F^{0.935}\ D$$

but when cutting test specimens of soft and hard cast iron the formula was

$$P = C\ F^{0.75}\ D^{0.935}$$

for his $\frac{1}{2}$, $\frac{3}{4}$ and $1\frac{1}{4}$-in. shank high speed round-nose tool. The latter agrees almost exactly with the authors' equation. Taylor's constants C were 45,000 for the soft cast iron and 69,000 for hard cast iron.

In order to compare data taken with the tool dynamometer with machinability data obtained by other methods, nine test bars 12 in. long were selected covering a variety of metals.

Comparison With Other Methods

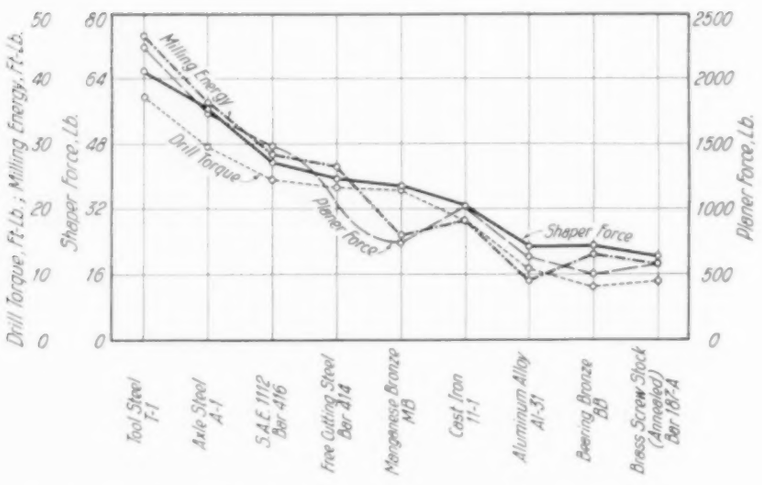
Each bar in turn was clamped in a shaper vise and the surface smoothed with another tool. The tool dynamometer was then inserted and the shaper set at a cutting speed of approximately 20 ft. per min. The feed ratchet was set to 0.006 in. per cut. A very light surfacing cut was taken with the dynamometer tool in order to get a good zero reading for depth, after which the tool was fed to a depth of 0.010 in. as indicated on a dial gage. Readings on all metals were obtained under this condition with tool "A." The tool left a very good surface on all metals and, except when cutting cast iron, no objectionable vibration was noted.

The nine metals tested are shown on the curve, together with the force on a standardized planer tool, the torque on a $\frac{3}{4}$-in. drill, the milling energy per chip of a standardized milling cutter, and dial readings on the tool.

The comparative accuracy of the device is immediately apparent, and it is significant that the total time required to prepare the specimens and make these tests was only about 5 hr. The planer-force curve for S.A.E. 1112 appears to be slightly high. The manganese bronze seems to show low values for the planer-force and milling-energy curves and rather high values for drill-torque and shaper tool dynamometer. The milling-energy curve for the aluminum alloy Al-31 seems to be low. In general, however, these various ratings compare favorably.

Influence of Cutting Fluid

A bar of annealed S.A.E. 3150 steel was cut with eleven different cutting fluids selected as representative and which have been reported on previously when planing, drilling and milling various metals. Each cutting fluid in turn was applied by hand from a large oil can in a steady stream at the point of cutting. When changing from one cutting fluid to another, the tool was not withdrawn from the work, although



Rapid Results With New Tool Compared to Machinability of Nine Metals as Determined by Three Other More Difficult Methods Which Were Described in Transactions A.S.S.T., November, 1929

the work was cleaned thoroughly. About one inch of length of bar was found to be ample for a single test.

Tests with the two tools, "A" and "B," were made for each of the eleven cutting fluids. The cutting speed was 66 ft. per min., the feed was 0.0069 in., and the depth of cut was 0.010 in. The stock was 1.808 in. in diameter at the start.

Two sets of tests were run with tool "A" and three sets with tool "B" (using all cutting fluids) in which the order of applying the cutting fluids was varied. The results are plotted in the figure.

It is interesting to note the difference in performance between tool "A" and tool "B." The cutting force using the sulphurized mineral oil No. 10 is practically the same for both tools. All other cutting fluids, however, show distinctly different values.

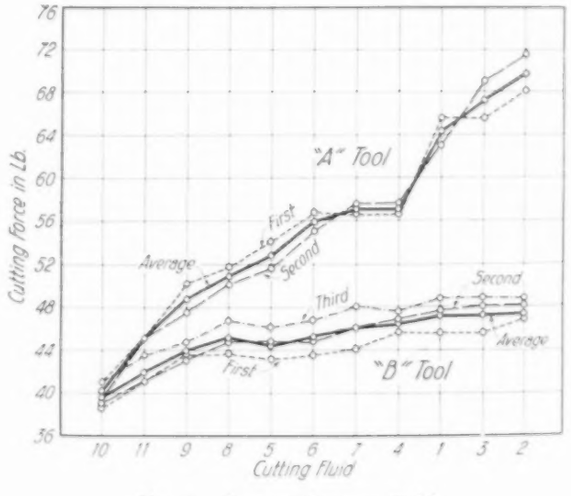
In similar work with tool "A," turning low carbon steel, the order of merit is 5, 10, 11, 8, 3, 9, 4, 6, 2, 7, 1. When drilling S.A.E. 3150 the order is 10, 11, 2, 3, 4, 7, 5, 6, 8, 1, 9. Relative value of cutting fluids therefore depends upon the steel, the tool, and the operation.

Machining Malleable Iron

It is known that the machining qualities of a malleable cast iron will vary from the surface to a depth of about 0.125 in., due to the decarburizing effect of the annealing process. This outer layer often is decarburized so that the metal at the surface consists of practically pure ferrite containing about 0.5% total carbon. Often the surface layers to a depth of about 0.020 in. will be found to be spongy and oxidized in spots. The carbon content gradually increases until a normal value for the interior is reached at the depth of approximately $\frac{1}{8}$ in. Perfectly malleableized iron will consist of temper carbon in a ferrite matrix; in practice, however, this matrix may contain pearlitic areas, and usually carbide particles will be found in varying quantities.

Machining qualities therefore depend on the distribution and relative quantities of these various constituents, the relative size of the grains, the presence of inclusions, sulphides, or phosphides, and will vary over quite wide ranges.

Force Necessary to Cut a Bar of S.A.E. 3150 Steel With the Aid of Eleven Different Cutting Fluids



No. 1. Dry cutting; no fluid
No. 2. 1½% borax in water (by weight)
No. 3. 1 part soluble oil in 50 parts water
No. 4. 1 part soluble oil in 10 parts water
No. 5. No. 1 lard oil
No. 6. Light mineral oil (mixed base)
No. 7. Heavy mineral oil (mixed base)
No. 8. 10% lard oil in paraffin base oil
No. 9. 5% oleic acid in paraffin base oil
No. 10. Sulphurized mineral oil (asphaltic base)
No. 11. Sulphurized lard oil with 5 parts of mineral oil (mixed base)

Previous work on a medium tensile strength iron gave machinability-depth curves for a planer tool, the torque on a counterbore, and the energy absorbed by a milling cutter tooth. These curves were roughly parallel, showing a pronounced maximum of force required at a depth of 0.040 in.

The object of the last series of tests to be described is to show how the tool dynamometer may determine these machining properties from the standard tensile test bars representing the heat. The eleven tensile bars used were cast from various heats in the same foundry, and represent commercial malleable irons.

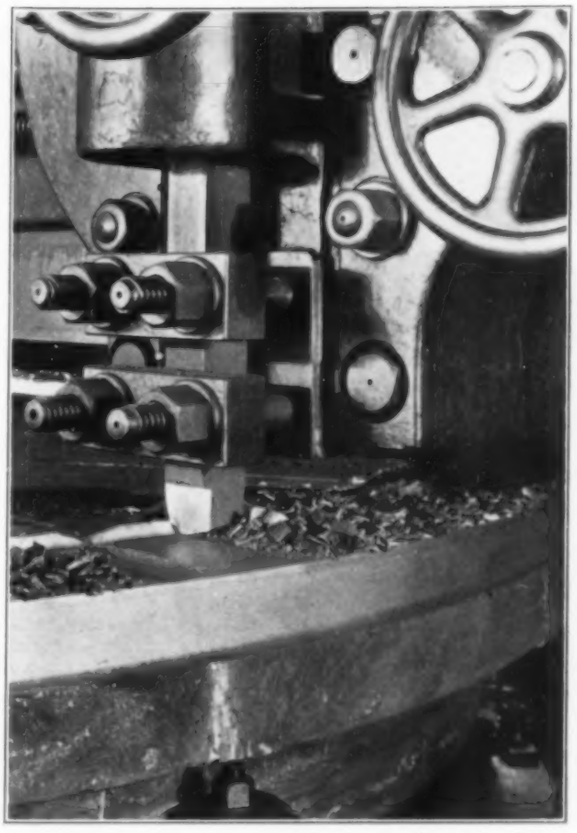
The bars were first very carefully centered and successive cuts, each 0.010 in. depth, were taken with a feed of 0.0091 in. per revolution with the "A" bit previously described.

Fifteen cuts were taken before the deflection due to the cutting forces became excessive. The diameter after each cut was determined by a micrometer, and the dial readings corrected to the full size of cut. Test data plotted against the distance from the surface to the center of the 0.010-in. cut show typical machinability curves for malleable iron.

In some bars the peak of machinability is much deeper in the metal, and the curve near the surface tends to flatten out. This indicates a much thicker band of nearly pure ferrite on the surface. The minimum points of the curves are also nearer the surface, indicating less diffusion of the carbon from the interior to the surface.

A decided drop of the curve immediately at the surface in four bars indicates a layer of spongy oxidized iron.

Humps in the curves are especially noticeable in two bars and invariably indicate incompletely malleableized iron. The microscope revealed free carbides and pearlitic layers. Although specimens were selected with total carbon contents ranging from 2.01 to 2.5%, there seems to be no correlation between carbon content and physical properties or machinability. Machinability values seem to depend not so much on analysis as on structure and, in malleable iron, structure depends on the annealing cycle, type of packing, and furnace gases present quite as much as on analysis. It follows then that for similar irons, a simple machinability test of this kind will tell much about the iron and will indicate what changes, if any, might be made to improve the product or to reveal the effect of experimental changes in the annealing process.



Courtesy Wm. Sellers & Co., Inc.

In conclusion it may be said that:

1. The tool dynamometer has been found to work equally well in a lathe or shaper.

2. Machinability ratings determined by it agree remarkably well with machinability tests determined by milling, drilling, and planing for nine different metals.

3. The amount of metal and the time required are much less than for other methods of tests.

4. Influence of a cutting fluid when turning a given piece of material can be determined with little time and expense.

5. The tool is valuable for determining the cutting characteristics of the skin or decarburized layer of malleable cast iron.

6. Relative machining properties of any group of metals may be determined quickly and at low cost.

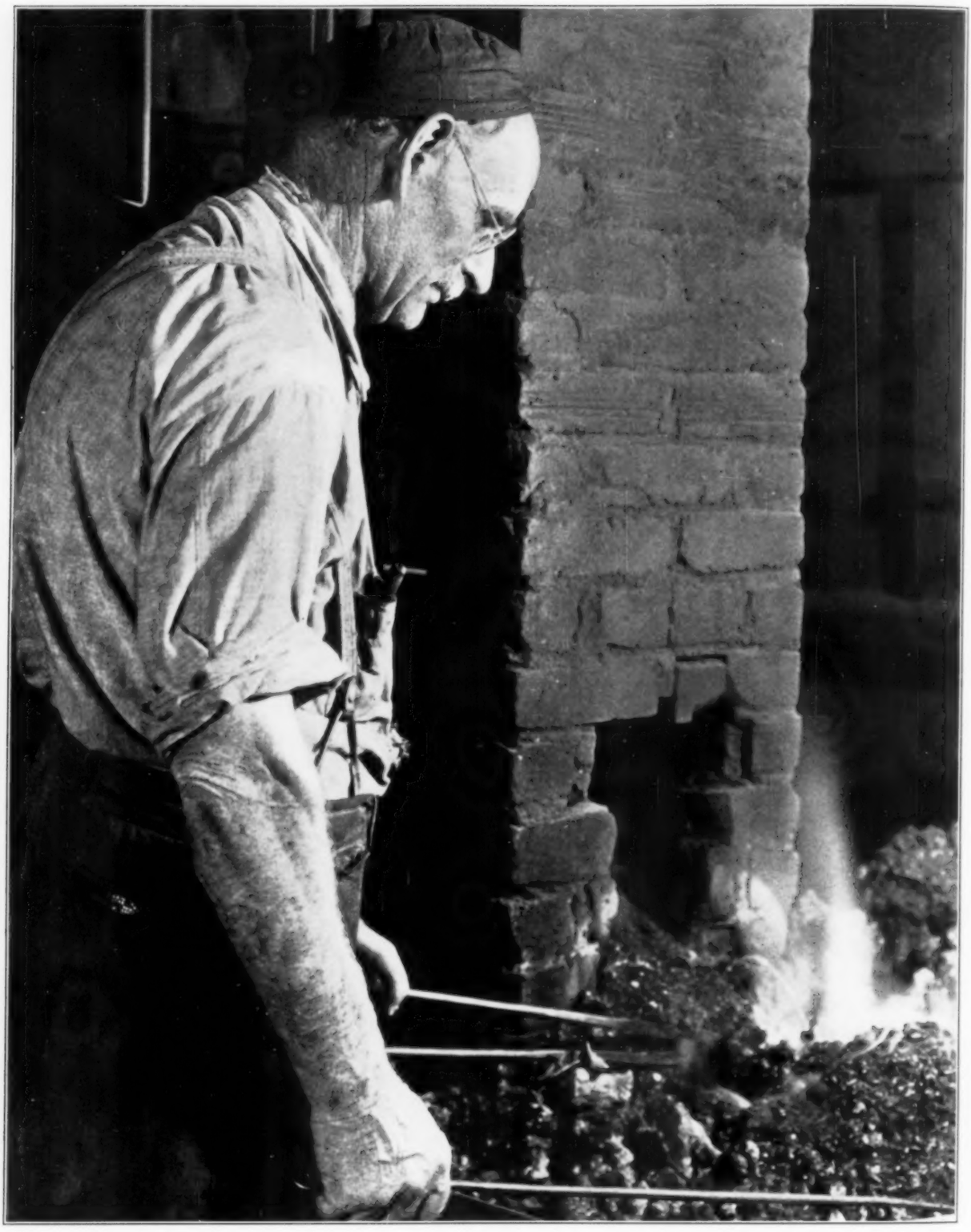


Photo by Lewis W. Hine

Patience and Skill

Information Wanted About File Testing

IT IS worthy of remark that little progress (other than a refinement in equipment) has been made for a score of years in the determination of metallurgical hardness. Some of the most interesting early sessions of the A.S.S.T. discussed this problem and the record makes interesting reading today.

Then, as now, the hardness tests gave but comparative measures of an ill-defined and complex combination of properties, which vary with the depth below the surface. Then, as now, methods in use attempted to determine the resistance to slow (or rapid) penetration by a small, hard-nosed tool, or the resistance to abrasion by a scratching implement or file. We have not even acquired terms for these two entirely different classes of hardness — "dentability" and "scratchhardness".

In fact we still rely upon a file to determine scratchhardness. It is the quickest, easiest performed and most reliable test for high hardness on large surfaces. Even though it is of little use in a precise specification, it is still extremely valuable for routine inspection, especially of quenched articles before tempering, and especially if the condition of the file after the test is also observed.

There must be some grounds for the widespread belief that scratchhardness is closely related to ability to resist wear and abrasion, for the testing file is used by makers of metal cutting tools, roller bearings and gears, and we frequently hear the statement that the more the surplus over file-hard, the better the article will stand up in service. If the file test had received the same attention that has been bestowed upon dentability, we would now be able to discriminate between various grades of super scratchard surfaces.

As a step in this direction it would be desirable to pool the information about the method of making the file test and its limitations. First, about the files: Doubtless the test depends upon the fineness of the teeth, their sharpness, shape and hardness. Must we depend upon the makers' guarantee that the files are "standard and uniform" (whatever those two words may mean) or is there any means whereby the user can determine this for himself? If he uses a test block, how should this be prepared, hardened and tested to make sure, it, itself, is "standard and uniform"? How dull can a file become before it is useless — that is, how many tests can a single spot make?

Second, about the operator: "File hard" depends upon the pressure and angle between file and object and the speed at which the file is moved. Which of these is important? Must we depend on the skill of a workman to regulate them?

Next about the object being tested: Its response to filing depends upon its shape and its chemical composition. Shape is infinite, but there ought to be some measurable differences between a ¼-in. drill and a tool-maker's flat. Also what influence has alloy or scale?

This last question leads to a suggestion that it might be possible to make files of a series of alloys or surface treatments which are believed to be pronouncedly different, and thus construct a scale of scratchardness. Thus — oil-hardening alloy steel, carbon tool steel, highly carburized tool steel, nitrided steel. Has anyone ever tried to make files in this manner?

Watch Latex

WITH an extraordinarily low price of the raw material, the American rubber manufacturers are eager to capitalize on their extensive researches into its manufacture and use. Hence the super-balloon tire. Its ready acceptance lends plausibility to the statement that the "springless" automobile is the next development, where doughnut tires will be attached to the chassis with rubber blocks. Rubber road surfaces are even mentioned!

In dozens of ways the wide-awake maker of

metals, tools, and machinery is able to use this interesting material, so it is unnecessary to suggest that he be continually on the lookout for up-to-date information about it. The developments promise to be even more rapid in the future, now that the chemists have discovered they can do so much more with latex (the unevaporated juices) than they can with caoutchouc, the gummy mass now used as a raw material.

We read enthusiastic predictions that latex will become the base of a wide-spreading industry. We are reminded that from ordinary coal tar have been developed all sorts of colors and chemicals, and that the humble cotton yields high explosives, "silks," celluloids, and food for stock and humans. Even though this pardonable optimism is sharply discounted, enough has already been accomplished with latex in the paper and textile industry to foreshadow interesting new finishes for metal.

Opportunities of Trade Associations in Reconstruction

TRADE associations by the hundred have been formed in the last decade. It would seem that no industry or no branch of industry is too obscure or too scattered to have one. Apparently a vigorous organizer has little difficulty in convincing the various pearl button manufacturers (for instance) that the advantages of getting together are worth a cash contribution once a year. In practice the theoretical advantages seldom accrue to the members, principally because of their own intense individualism.

Technical associations are far fewer in number, but correspondingly greater in importance. Their maintenance depends entirely upon good will and public spirit. The fundamental idea is that each member gives a little of his resources in knowledge, time and money, and each one gains by sharing in the pool so formed.

Hence arise the differences in activities and outlooks. A big majority of the trade associations endeavor to maintain the status quo. The public hears them frequently and vociferously demanding that the anti-trust laws be modified so the industry can be "regulated." Technical associations, on the other hand, are quick to broadcast news of developments in equipment, manufacture, or processing that tend to upset conventional ideas and practices. The business men's tendency is to stabilize affairs on a comfortable level of mediocrity. The engineer and technician's endeavors plainly conform to the evolutionary trends of all human development.

Doubtless these divergent influences reflect an equally pronounced difference in mental attitude of business man and technician. The one is inclined to believe that what is his is his, and he owes nobody anything for it. The other knows all too well that the present body of knowledge in every-day use is an accumulation of the labor and thought of an unnumbered and unknown multitude — without their silent help the individual would be merely a savage.

So it happens that in these days when new products oust old ones from traditional uses, when acceptance specifications become increasingly stringent, when style, form, and color have greater selling value than strength and durability, when the cream of an industry is skimmed by a few intelligent organizations, when much would be gained by joint efforts in research, advertising, development, the trade association, with a few honorable exceptions, is incapable of sustained work on any of these lines.

Now, with the valley of the depression passed and a hopeful future ahead, is an opportunity for those engineers and technicians who have turned executives to remedy this situation. They can see both the advantages of associated effort and the folly of isolation. Let them act quickly and energetically. Otherwise, the large corporation, large enough and intelligent enough to function independently in the essential research, advertising, and development, will gather to itself all the profitable business, leaving barren husks to the small competitor.

By J. P. Gill
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Deep Acid Etch Test

an interpretation for tool steels

Abstract of a paper for Buffalo Convention, A.S.S.T., October, 1932

DEEP acid etching of steel is constantly gaining favor as a method of inspection. The consumer usually interprets it as to whether the material is satisfactory from his viewpoint. To the producer the test is of immensely more importance; when properly correlated with other tests it may indicate the nature of defects and their cause.

Since every steel is a heterogeneous mass —made up of mixtures and chemical compounds, non-metallic and metallic segregates —every steel is subject to a selective attack by the strong acids. Different acids attack different constituents. It therefore results that steels which appear solid and free of inclusions when etched with one acid may appear spongy and with many inclusions when etched with another.

Recommended practice of the A.S.S.T. is given in the Handbook, 1930 Edition, page 415. The solution recommended is composed of one part hydrochloric acid and one part water and is to be used at a temperature of 160° F., the steel immersed in accordance with a time table. For tool steels the time recommended is from 30 to 45 min. according to composition. Hydrochloric acid was selected due to the fact that it undoubtedly has greater selective etching properties than any other single acid and because evaporation at 160° F. does not change materially its concentration.

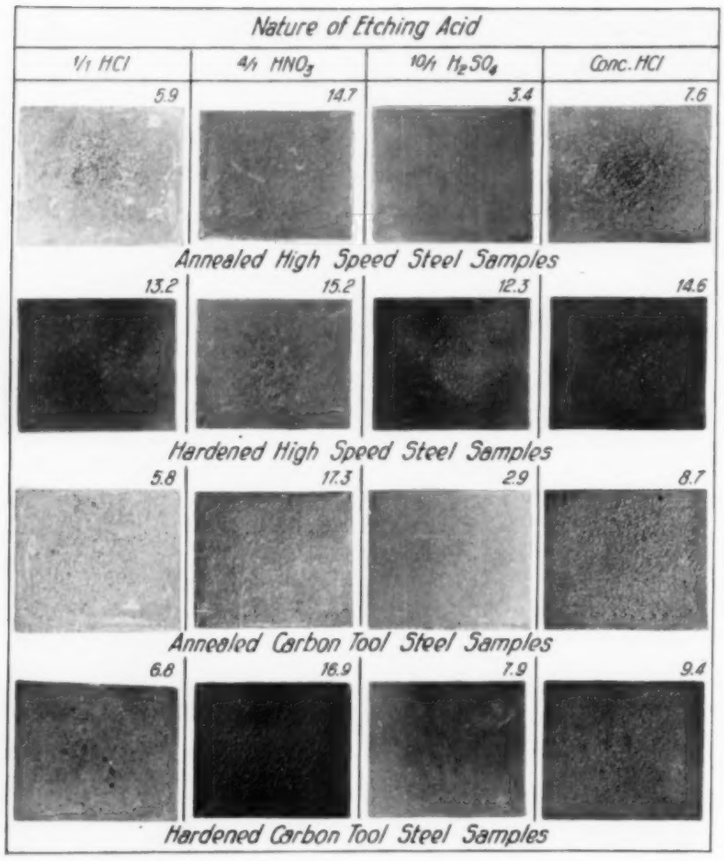
To visualize the fact that tool steels react differently with different acids the following experiments were made:

Two steels, one an 18% tungsten high speed tool steel and the other a 1% carbon tool steel, were selected. Choice was based on the fact that in the above described standard HCl etch the high speed steel showed a pronounced degree of apparent sponginess, and the carbon tool steel showed a number of small holes which were indicative of non-metallic inclusions.

The high speed steel specimens which were heat treated were preheated to 1550° F., rapidly heated to 2340° F., quenched in oil and drawn at 1060° F., for 2 hr. The 1% carbon tool steel samples which were heat treated were quenched in brine from 1430° F. and drawn for 2 hr. at 350° F. Specimens were machined to approximately $1\frac{1}{4}$x$1\frac{3}{8}$x$\frac{1}{4}$ in. and were cut adjacent to one another.

Ten specimens were cut and after numbering in consecutive order as cut from the bar, the specimens numbered 1, 5 and 10 were subjected to the standard acid etch and compared. As an additional guarantee of similarity, $\frac{1}{16}$ in. was removed from the specimens which were originally etched in sulphuric and nitric acids and then etched in the standard HCl etch. These tests showed conclusively that all of the specimens, when etched in hydrochloric acid, showed a comparable and similar condition.

All heat treated high speed steel specimens had approximately 0.020 in. removed from each surface after heat treatment and before etching.



Samples in Horizontal Lines Are of Same Steel; Samples in Vertical Lines Are Etched in Same Manner. Figures give % loss in weight. Reduced one-third

while the carbon tool steel specimens had approximately 0.010 in. removed.

All specimens were heated to 180° F. in water and after reaching this temperature they were transferred to the etching solution which was at 180° F. and held for 30 min. The surfaces adjacent to those etched with hydrochloric acid were etched with nitric and sulphuric acid; consequently, these surfaces were separated in the bar only by the width of the saw cut. The photograph on this page shows the results.

In the photograph, "etched by 1/1 HCl" means that the specimens in that column were etched in 1 part water to 1 part HCl by volume. The nitric acid etch was 4 parts water to 1 part HNO_3; the sulphuric acid etch was 10 parts water to 1 part H_2SO_4.

A careful study of these specimens indicates quite clearly that if they had been etched in either HNO_3 or H_2SO_4 they would have been considered excellent, while if etched in HCl would probably have been undesirable (even though the specimens etched in HNO_3 lost approximately double the weight of the specimens etched in 1/1 HCl). Are we justified in condemning a piece of steel which shows apparent sponginess when etched in hydrochloric acid and no evidence of sponginess when etched in nitric or sulphuric acids? It is obvious that hydrochloric acid has attacked the specimens selectively to a much greater degree than either of the other acids even though the amount of steel dissolved in hydrochloric acid was between that dissolved in nitric and in sulphuric acid.

Although hydrochloric acid shows a much greater selective attack on most tool and special steels, nevertheless there are other steels where mixed acids will act much more severely. Outstanding examples are those steels having a high aluminum content. When aluminum oxide is present in these steels it is not indicated by the standard hydrochloric acid etch.

For illustrations we show on page 40 specimens of nitralloy of the following approximate composition: C 0.25%, Cr 1.40%, Al 1.20%, Mo 0.20%.

The square specimens are of one heat and the round ones of another. Photographs are of adjacent transverse sections of one bar. Specimens at the left were given an identical standard one-to-one hydrochloric acid etch; the others were etched for one hour at 180° F. in an aqueous solution containing 10% hydrochloric acid and 2% nitric acid (solution developed by V. T. Malcolm of Chapman Valve Mfg. Co.). It is difficult to believe that the round photographs could be surfaces of the same bar adjacent to one another!

An electrolytic analysis made by the U. S. Bureau of Mines on these samples showed that the heat from which the square bar was made contained 0.007% Al_2O_3 while the heat from which the round bar was made contained 0.015% Al_2O_3. This is a most excellent example of a

case where a consumer using a standard HCl etch would not have noted the presence of the large amount of aluminum oxides in the steel.

Rate of solubility in acid is dependent to a considerable degree upon the structural condition of the steel, that is, whether annealed, hardened, or hardened and drawn. Furthermore, in steels which are so highly alloyed as to be of a segregated nature, such as high speed steel, 2% C.-12% Cr. steel, tool steel and ferritic stainless steel, etching will proceed at a greater rate at the point of contact between the segregate and the matrix and many times the segregate will actually be etched out, leaving an apparent pit, and an etching solution many times containing a finely divided black substance.

Specimens of highly alloyed steels ordinarily react to the hydrochloric acid etch much differently when in the hard state, since a large part of the segregate is dissolved in the matrix and the hardened steel is more homogeneous.

As representative of this class of materials an 18% tungsten high speed steel was selected to show the effect of hardening and also to prove that the pin holes appearing particularly in the annealed specimens were the result of etching out the segregate. Three 2-in. bars of high speed steel of quite similar composition were selected, which in the annealed condition when etched with hydrochloric acid indicated three degrees of porosity; bar 17 was classed as "good"; bar 18 as "intermediate" and bar 19 as "spongy". Close examination of annealed and etched bar 17 showed very small pits over the entire surface; from these pits came a segregate which was collected and analyzed. Our investigation also showed that the apparent sponginess in bars 18 and 19 was chiefly the result of the segregate etching out of the specimens and not due to non-metallic inclusions. Specimens were approximately $\frac{1}{4}$ in. thick and the heat treated specimens had 0.020 in. removed from the surface after treatment. The group of photographs on page 41 was made after the standard hydrochloric acid etch.

Pieces about $1\frac{1}{4}$ in. square, weighing about 60 grams, were then cut from the center of these disks and immersed in 1-1 HCl at 170° F. for 21 hr. Volume was maintained at 500 c.c. The fine residue was separated and a quantitative analysis made of both the residue and the filtered acid. Results are contained in the accompanying tabulations, wherein "A" means annealed specimen, "T" means heat treated specimen.

It is interesting to note that the analysis of the residue of the annealed steel corresponds closely to the double carbide of iron and tungsten represented by Westgren's formula Fe_4W_2C. The iron, as found by us, is somewhat lower and has apparently been replaced by chromium and vanadium, thus forming complex carbides of Fe, W, Cr and Va.

There is not enough difference between the residues to account for the difference in sponginess found in the annealed condition. Apparent sponginess can most likely be explained by the degree of segregation; especially is this true for bars 17 and 19. It seems that the greater the segregation the greater the selective etching and therefore more apparent sponginess.

A noticeable difference does exist between the analysis of residues in the annealed and in the heat treated conditions. Carbon content of the residue from the heat treated samples is about two-thirds as much; a drop in the other alloys is also noted. There is little change in the percentage of chromium dissolved although there is a considerable increase in the percentage of

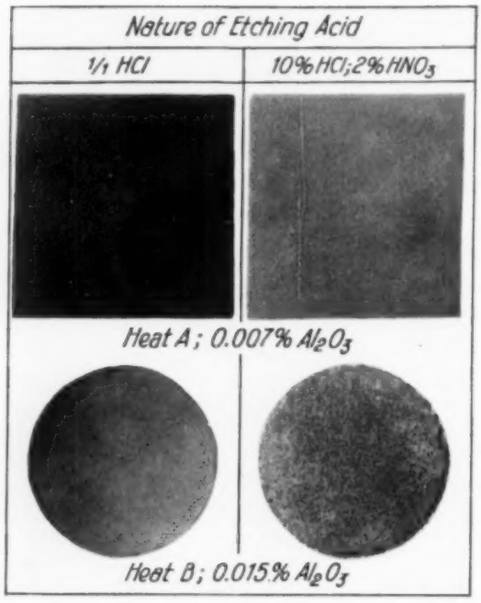
ACTION OF HOT ½ HCl FOR 21 Hr.

	Undissolved Steel	Fine Residue	Metal Dissolved
Bar 17-A	41.6%	15.8%	42.6%
Bar 18-A	48.5 (perforated)	13.3	38.2
Bar 19-A	39.2 (perforated)	15.9	44.9
Bar 17-T	13.3	24.2	62.5
Bar 18-T	17.8	23.0	59.2
Bar 19-T	3.3 (center gone)	26.5	70.2

CHEMICAL ANALYSES OF RESIDUES

Sample	Carbon	Tungsten	Chromium	Vanadium
Analysis of Bar Stock				
17	0.70	17.72	4.09	0.97
18	0.67	17.60	3.93	1.00
19	0.70	17.53	4.15	0.98
Analysis of Fine Residues				
17-A	2.14	62.06	3.44	1.95
18-A	2.22	63.40	3.26	2.26
19-A	2.16	60.98	3.32	2.39
17-T	1.62	60.05	2.56	1.56
18-T	1.42	53.15	1.68	1.56
19-T	1.52	58.29	2.42	1.70
Analysis of Metal in Solution				
17-A		0.47	3.88	0.20
18-A		0.36	3.65	0.20
19-A		0.62	3.84	0.14
17-T		1.77	3.61	0.61
18-T		1.60	4.07	0.81
19-T		1.79	4.36	0.60

tungsten and vanadium from the heat treated samples (as would be expected due to the greater solubility of these elements in gamma iron). We noted that the heat treated samples did not etch with the same porosity as did the annealed samples, due to the solution of the segregate on hardening. It should also be noted that the degree of solubility, as represented by the percentage loss in weight, is not in accord with the degree of sponginess found.



Hydrochloric Acid Does Not Indicate High Content of Al_2O_3 in Steels for Nitriding as Well as Mixed Acid

Now that it has been pointed out that the interpretation of the deep etch test requires skill and experience, that a bar which seems porous after pickling in one acid may appear quite sound after pickling in another, and that "porosity" may be due to segregates or carbide particles as well as to non-metallic inclusions, a few brief remarks may be made upon defects and characteristics revealed by deep etching. The literature contains many papers treating of the cause of such structures.

Etching Cracks — Highly stressed steel can be cracked by the solution itself; HCl is more active in this respect than either HNO_3 or H_2SO_4. Therefore bars and forgings should be annealed, and hardened steels drawn at least to 300° F. before being etched.

Open Grain — For lack of a descriptive term, the condition found in the center of the left hand photographs on page 42 may be called "open grain". It might also be termed surface roughness and many term it sponginess. This condition is the one which has probably led to more contention between the consumer and the producer than almost any other condition revealed by the deep acid etch. Specimens which show this condition when etched in hydrochloric acid do not show it when etched in nitric or sulphuric acids. Such a condition, therefore, does not represent a discontinuity within the metal but is the result of selective etching by the reagent.

Segregation is controllable within limits by ingot size, mold wall, casting temperature, and deoxidizers, all of which influence the method of crystallization and the distribution of segregates both metallic and non-metallic. Since oxide inclusions may act as nuclei for crystallization, steel having high oxide content often shows less "open grain" than comparatively clean steels. When "open grain" structure is revealed by the etch it is advisable to examine the steel at low magnification, and if inclusions (particularly sulphides and silicates) are not present in abnormal amount, the steel should be considered satisfactory.

Pattern Effect — The same samples show a pattern of some symmetry. It is almost wholly the result of crystallization characteristics of the ingot; the columnar shell etches differently from granular core. There is sometimes a concentration of sulphides and silicates in the area of contact between these zones, when the outline is much more sharply defined.

Pipes and Hammer Bursts — These are usually visible without etching, but etching will distinguish between the two. Little or no sponginess is shown around a true burst, while material which is piped (an ingot defect) is spongy in the adjacent areas.

Center Porosity is due to selective etching both of inclusions or segregates, and is found in widely varying degrees. Whether steel showing this condition should be used is a matter of experienced judgment — if used so the outside of the bar is likely to be the working part, then this condition, unless excessive, should be of little consequence.

Unkilled Steel — Such steel shows numerous blow holes and non-metallic inclusions indicative of gases and oxides distributed throughout at the time of casting.

Non-Metallic Inclusions appear as pits in an etched sample of "killed" steel and must be distinguished from pits due to metallic segregates. If suspected, then samples in both hardened and annealed condition should be etched and compared. Etched steels containing non-metallic inclusions appear much the same after hardening as in the annealed condition. As noted above, 10% HCl + 2% HNO_3 is sometimes useful for showing inclusions in some alloy steels.

Metallic Segregates — All highly alloyed steels contain a varying amount of metallic segregates and the manner in which such steels react to the deep acid etch is fully described in the experiments on the etching of 18% tungsten high speed steels.

Internal Cracks are sometimes called flakes, chromium checks, hair line cracks or cooling cracks. They are an actual discontinuity in the metal. This condition is rarely found in carbon tool steels; it chiefly affects steels with intermediate alloy content having only slight air hardening properties. While there is a difference of opinion as to the exact cause, slow cooling invariably prevents it in a large class of steels.

Dendrites are ingot crystals not eliminated in subsequent working. It is significant that carbon tool steels which appear highly dendritic are usually exceptionally clean and free of oxide inclusions. If phosphorus and sulphur are very low (whose distribution is affected by the dendrite) the structure is probably of no serious consequence.

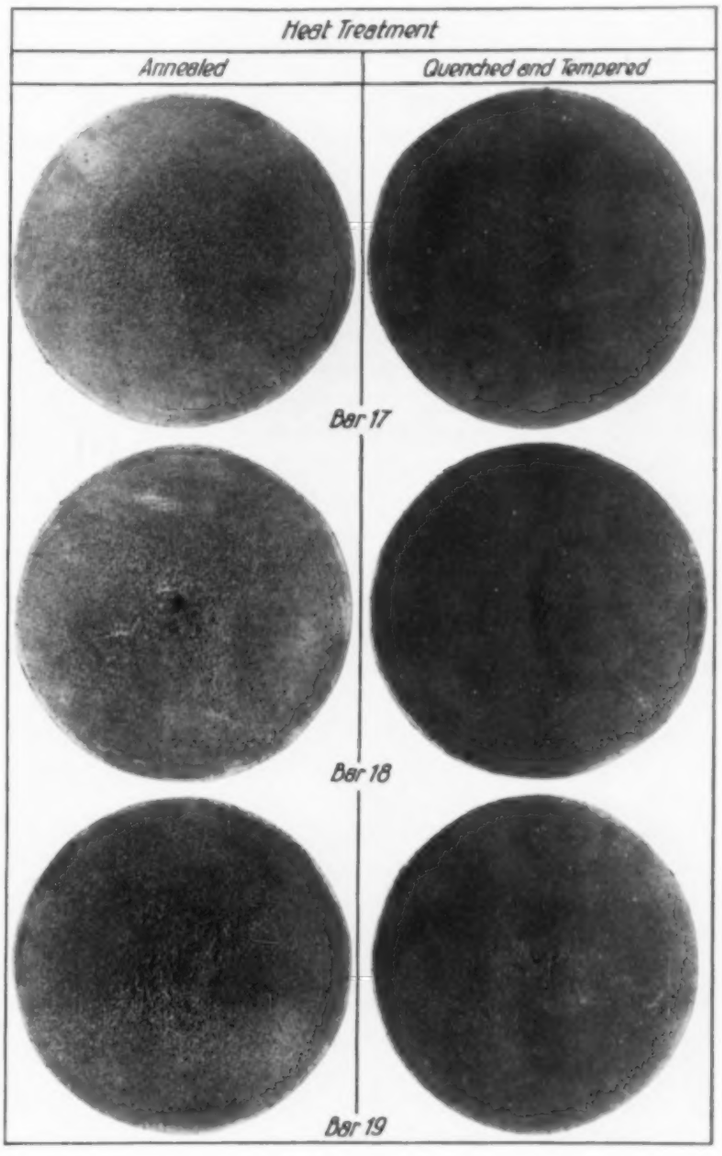
Grain Size — Deep acid etching is of little value in determining this, unless the grain is highly enlarged, when the specimen will have a mottled appearance.

Decarburization — Decarburized areas usually etch much less rapidly than their surroundings and are considerably lighter in color. Long etch will bring them into relief. A mild etch will develop this condition better than the standard hot HCl etch.

Carburization — Opposite appearances to the above, after a mild etch, indicate high carbon areas.

Hardened Case — In shallow hardening steels, such as carbon and carbon-vanadium tool steels, an excellent contrast can be obtained between the case and the core by mild etching.

Flow Lines — If a specimen is cut longitudinally from the bar, etching will develop streaks and striations due to elongated metallic and non-metallic inclusions and segregates. (Specimens which are selected for deep acid



Discs From 2-in. Bars of 18% High Speed Steel Etch Differently in 1/1 HCl When Annealed and When Hardened

etch are usually taken across the section; consequently only the ends of rolled-out inclusions, or segregates are visible.) Such streaks and striations are sometimes called "flow lines" as they indicate the direction in which the steel was worked. This characteristic may prove valuable in determining whether or not a piece has been forged to shape or has been cut to shape; a classic example of this is determining the method of manufacture of crank shafts and gear blanks.

They are always visible to a more or less degree, therefore they do not signify a defective material unless the striations show a highly selective etching, when further examination for inclusions or segregates should be undertaken. (Cederleaf and Sanders have recently shown that forging practice has considerable influence on the ease with which flow lines may be etched in 1/1 HCl at 140° F. See METAL PROGRESS, for July.)

Surface Defects — Etching will sometimes develop surface defects which may not be visible otherwise. Seams are not deep, and are elongated in the direction of working in a thin line. Cooling cracks in self-hardening alloys are very deep; shallow ones may rarely be found in other types of steel. Short seams may be called "flakes." Laps, caused by a fold in the worked metal, are easily distinguished from seams; in an improperly rolled bar they recur with considerable regularity. They usually result from cracked billets or improperly prepared billets.

Soft Spots — These often occur in hardened carbon or carbon-vanadium tool steel. In the standard etch they almost invariably are in relief and are not as dark as the surrounding areas.

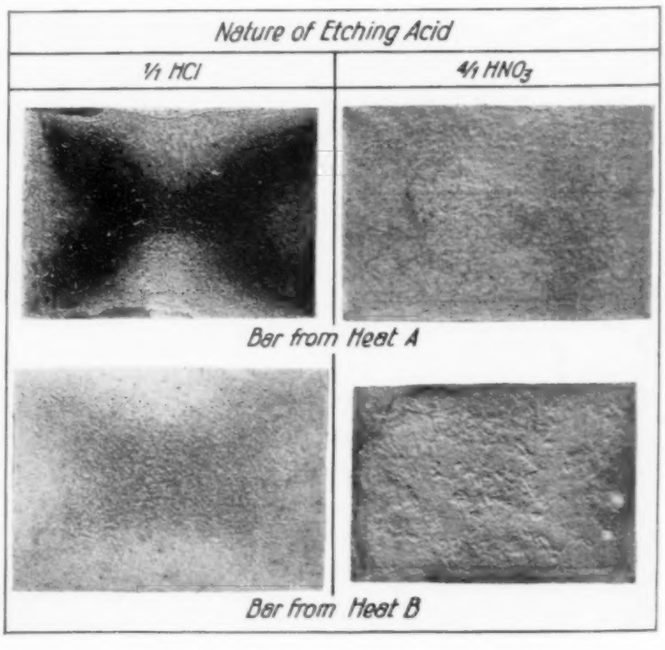
Composite Steels, which may be made up of high carbon and low carbon plies, and steels which may have inserts of a composition different from the surrounding material, can readily be distinguished by the standard deep acid etch. Structure of inferior wrought iron is also shown in this manner.

Grinding Cracks developed after etching usually form a pattern of some symmetry.

In conclusion it may be said that the deep acid etch test reveals readily and quickly many of the characteristics of steel but in some instances they require further examination by standard testing methods and under the microscope to evaluate them properly. The knowledge of the fact that a piece of steel is dendritic or contains metallic or non-metallic segregates is in itself insufficient evidence to base a definite conclusion about the properties of the material or to warrant rejection.

It has real value when used to separate materials which are obviously defective from those which are not. It has a further value in indicating characteristics which do not obviously make the material defective but which indicate that the steel should be investigated further.

It is one of the most simple of tests yet undoubtedly requires more experience and judgment to evaluate than any other method of testing. When used by the inexperienced it is one of the most dangerous methods of testing ever devised, in that the conclusions are often a matter of opinion, the value of which can be no greater than the experience and judgment of the investigator.



Adjacent Surfaces of 2% Tungsten Tool Steel Show Open Grain and Pattern Effect In One Acid and Etch Uniformly in Another That Does Not Attack Segregate Borders

By Ernest E. Thum
Editor, Metal Progress

Brittleness under slowly creeping stress

IN THE THREE issues of METAL PROGRESS just passed have appeared discussions of the cause of failure of heat treated bridge wire — material which passed all the acceptance tests yet which broke in service at very low unit loads and fortunately before the bridges were completely erected. Evidence was presented against the suppositions that the failure was due either to abuse in erection, overstress, or fatigue in service, or to bad steel, or abuse in manufacture, causing accidental or sporadic blemishes, or to non-permanence of properties.

It is conceded, of course, that the very existence of broken wires is proof positive of an overpowering stress. The location of all the breaks at or near the edge of anchorage shoes or suspender clamps means that the whole wire was affected, each inch of it. By its very nature heat treated wire must be incapable of withstanding stresses gradually increasing in intensity. Without having any experimental evidence to back the statement (other than the behavior of the wire in the bridge and some tests on the wire made after the cables were dismantled) it is the belief of the present author that quenched and tempered eutectoid steel cannot endure a slowly creeping load.

This weakness of the material was intensified by the surface condition of this particular wire, and therefore the failure at the Mt. Hope and Detroit bridges may be a combination effect of an improper surface and a microstructure incapable of stopping the rapid extension of a surface crack. The matter of surface roughness and hydrogen brittleness is reserved for future discussion. But we might as well remember that it is not possible to make wire commercially with a *perfect* surface, absolutely free from inclusions or irregularities.

A good deal is known about quenched and tempered wire because it is the principal raw material for moderate sized springs. A closely allied material in the form of cold rolled strip, quenched and tempered, has been the standard material for motor springs for clocks and phonographs. Consequently, we are immediately able to say that quenched and tempered eutectoid steel is not brittle under loads applied at high rate, under loads applied at moderate rate, or under loads applied at zero rate (i. e., quiescent loads).

For instance, in the manufacture of springs quenched and tempered wire is formed, bent, and curled at rapid rate. Loads stressing the metal far beyond the elastic limit are applied in a fraction of a second. The same kind of stressing was endured successfully by long lengths of the heat treated bridge wire, when it was wound rapidly around a mandrel four wire diameters in size. It follows that quenched and tempered wire is not brittle under rapidly applied loads.

Springs in operation — valve springs, for instance — carry rapidly vibrating loads successfully as long as the intensity is less than the endurance limit, and as long as they are

not corroded. Quenched and tempered eutectoid steel, therefore, is not inherently brittle under loads rapidly varying in intensity.

Neither is such material brittle under loads applied at a moderate rate, such as the speed of tension testing or twisting or preforming for the anchorage. No suspicious troubles of this sort were encountered when testing each end of each length of wire, as required by the specifications, nor in many tension and torsion tests conducted since that time.

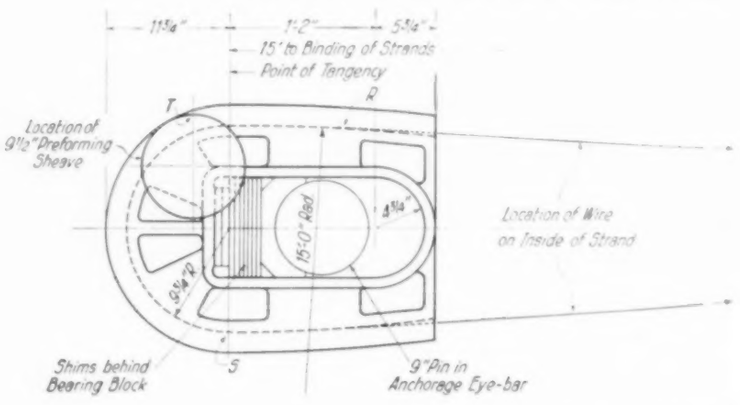
Nor is quenched and tempered wire brittle under stationary loads, even though very high. Several loops of the heat treated wire endured loads of 180,000 lb. per sq.in. (approximately its yield point) for over a year without failure except at the grips. This fact is further verified by clock makers' lore: Clock springs are wound to such a sharp curvature that the strip, if released, will not entirely uncurl — that is, the strip is stressed beyond its elastic limit at the extreme fibers. But the spring is not released after winding; it is slipped into a keeper or wire loop which maintains that spring under high stress continuously. Such springs, of well-made eutectoid steel, do not break even when stored for months, unless there is definite evidence of surface corrosion. Heat treated steel is therefore not brittle under quiescent load, even beyond the elastic limit.

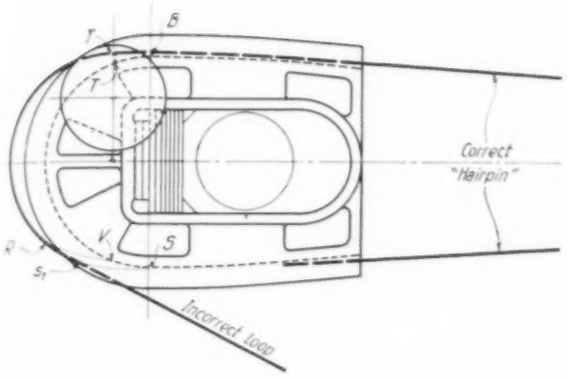
It should be pointed out, however, that the failures at Mt. Hope occurred in wire stressed beyond the yield point at the outer fibers, to which was added a very slowly increasing load — a "creeping" load, it might be called — essentially different from any of the types of loading mentioned above.

This statement requires some elaboration. The stresses in the quenched and tempered wire, while on the reels as delivered to the bridge site, were considerably below the yield point. (The outer fiber of a 0.195-in. wire bent around the surface of a 6-ft. drum is under a unit stress of about 77,000 lb. per sq.in.) This means that the wire, on unwinding, lay straight. Furthermore, it was very "springy" — that is, its elastic limit was so high that the wire did not snug up to the curvature of the 19½-in. diameter shoe until the weight of the wire reaching to the other anchorage pulled it up, or unless the men at the anchorage first bent the wire around a 9½-in. diameter sheave. This stretched the outer elements beyond the yield point in tension and the inner elements beyond the yield point in compression, causing plastic flow in these two extreme segments of the cross-section. After so forming and loosening, the wire sprang back to a hairpin shape with radius of the bend approximately 10 in. It is probable that the internal stresses in the preformed or bent portion of the wire are of moderate intensity, possibly not greater than the internal stresses in a straight piece of wire. It is in the same condition as a spring after forming and after "springing back" to free length or diameter.

But consider the circumstances existing in a hairpin of bridge wire when the preforming was not done with great precision. The preforming sheave appears to be set too far back, and the point of tangency *T* of the loop does not correspond to the point *B* where the wire coming from the bridge actually began curving around the 9¾-in. anchorage shoe. Many loops removed from the bridge were a little too short; that is, instead of the tangent wires intersecting some 15 ft. ahead, they actually diverged. The condition is sketched, showing that tangent point *R* on the wire loop does not meet the point of tangency *S* at the exit end of the shoe curve. It is clear that short portions of straight wire, such as V-S and T-B, were pulled from straight into an arc of 9¾-in. radius when the wire was strung to the other bank, and this load was

Scale Drawing Showing Actual Location of Preforming Sheave on Anchor Shoe at Mt. Hope Bridge





Sketch Showing Approximate Location of Loop of Wire After Preforming Too Short

never relieved. In those places, the outer bend of the curve would be stretched 1%, much beyond the yield point. This means that a small segment of metal in any cross-section of wire at these critical regions has been stressed up to the elastic limit, has suffered a certain amount of plastic deformation, and, since the load continues unabated, continues to carry a load approximately equal to the "long-time elastic limit." (The stress distribution is shown approximately in the upper right-hand diagram.)

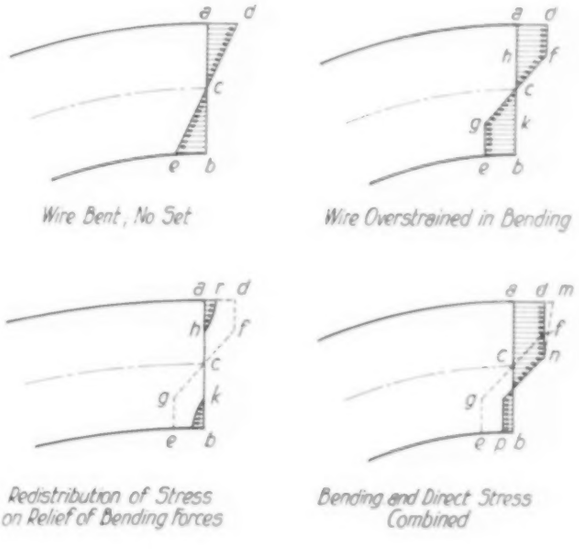
Of course, some redistribution of stress in the single wire occurs as the metal surrounding the overstrained elements adjusts itself to the localized elongation of the extreme fibers, but it is believed that the essential difference between quenched and tempered wire and cold drawn wire is this: That the former is so hard and unyielding that the overstrained portion (between point *d* and *f* in the diagram) gets little or no relief as long as the load persists, but continues to carry a load dangerously close to the ultimate, whereas the fibrous hard drawn wire soon readjusts its internal organization so that these excessive internal stresses are relieved. At any rate, the yield point of the quenched and tempered wire as determined by tensile tests, at 180,000 to 190,000 lb. per sq.in., is within 35,000 lb. of the ultimate strength, whereas cold drawn wire will acquire a permanent set at 103,000 lb. per sq.in. (at least 120,000 lb. below the ultimate strength). The correct figure is even lower than a precise stress-strain curve would indicate, for cold-drawn wire acquires a permanent curve after winding on a 6-ft. reel. Clearly, hard drawn wire possesses a much larger margin of safety at these places where the wire bends into a curve and takes a permanent set.

It may be argued that the mere fact that certain fibers in limited portions of the wire were stretched beyond the elastic limit by an unrelieved load should not have caused ultimate rupture, any more than a wound clock spring in its keeper should break under its heavy but quiescent load. But remember that this bridge wire, as soon as the cable spinning was completed, was subjected to a slowly increasing load imposed by the gradual erection of the suspended span. In other words, a portion of the wire, already at or near the long-time yield point, is enduring not a quiescent load but a creeping load, which is little by little growing greater.

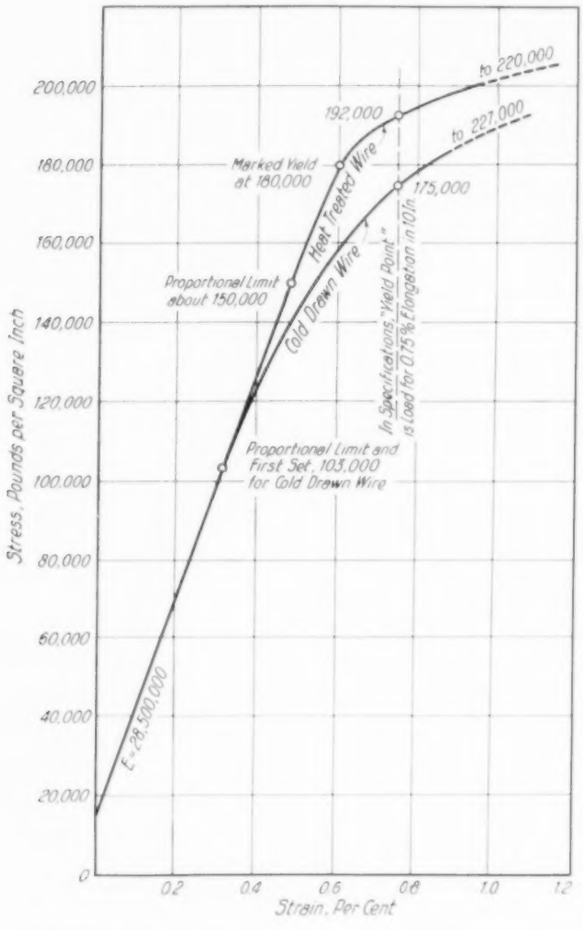
This stress condition is sketched at the lower right of the group just below. It is postulated that quenched and tempered eutectoid steel, which is predominatingly troostite and containing no ductile ferrite crystals, is unable to adjust its internal organization to resist such a creeping stress, and it will crack in the outer bend, in the most highly stretched element whenever the stress *d-m* equals the margin between elastic limit and ultimate strength, and this crack will work its way very rapidly (perhaps instantly) across the wire.

On the other hand, an incipient crack in

Approximate Distribution of Stress in Wire Which Has Been Bent and Loaded



cold drawn wire would be stopped almost as soon as it starts. In this characteristic cold drawn material is like wrought iron, tough in cross bending because it resists the propagation of cracks. A "crystalline metal," in the words of the late J. E. Howard, does not retain its toughness at the root of a crack; a "fibrous metal" does. B. P. Haigh couches the same thought in more scientific language in a lecture before the Faraday Society, 1928. He said, "Plastic flow in cold worked metals, far from being a source or symptom of danger, is probably quite the reverse in respect that the associated slipping not only hardens the metal but may often discount the dangerous influence of notches and other discontinuities of section. In more elastic metals, such discontinuities may produce local concentrations of stress approximating to those indicated by mathematical or optical analysis, and may so cause premature fatigue and fracture."



Typical Stress-Strain Curves for Cold Drawn Bridge Wire (According to Moisseiff) and for Heat Treated Wire From Mt. Hope Bridge

The theory outlined above would require that the trouble would develop quickest where the overstrained metal was greatest in extent (at the sharpest bends) or where there was the least lateral freedom to permit adjustment of the internal organization of the wire. These conditions exist at and under the suspender castings, where the wires are compacted and squeezed together permanently under high pressure. The general change in compactness in the cable at the edges of these castings would cause some short bends in some unfortunately placed wires. Here we would expect to find breakage. Many breaks were, in fact, found in just such locations in the Ambassador bridge, when the creeping stresses amounted to much less than 10,000 lb. per sq.in. Breaks at the anchorages would be slower in developing, for the curvature was less sharp. They occurred when the creeping stresses totaled 32,000 lb. It may be significant that this is just about the margin between the yield point and ultimate strength, as determined by tension tests. No breaks occurred at the columns or "cable bents" where the wires were bent over saddle castings with long-radius curves which stressed the outer elements of the wire less than the elastic limit. There the combined stresses due to bending and direct tension were not yet at the yield point.

The theory also would account for the fact that the breaks were distributed among almost all the anchorage shoes. This would be due to lack of precision in preforming.

Concentration of 140 broken wires in one strand and 130 in another is explainable by supposing that two heats of steel were definitely lacking in quality. (See METAL PROGRESS, August, page 32.)

The great epidemic of breakage on Feb. 22 may reasonably be ascribed to the snow storm and cold snap the night before; the low temperature undoubtedly decreased the already deficient ductility of the wire. It might also be due to the opportunity the resident engineers had of making a more leisurely and thorough examination on the holiday.

When emergency measures had relieved the stress on the bent wires by 20% (down to approximately 25,000 lb.) the breakages ceased.

In other words, creeping stress was relieved.

It would appear, therefore, that the theory advanced—namely, that heat treated high carbon wire is brittle under creep stress slightly above the elastic limit—accounts for the occurrences recorded at the two bridges. Tests did not determine this condition because the loading in a testing machine is at an infinitely greater rate than the creeping load of bridge erection.

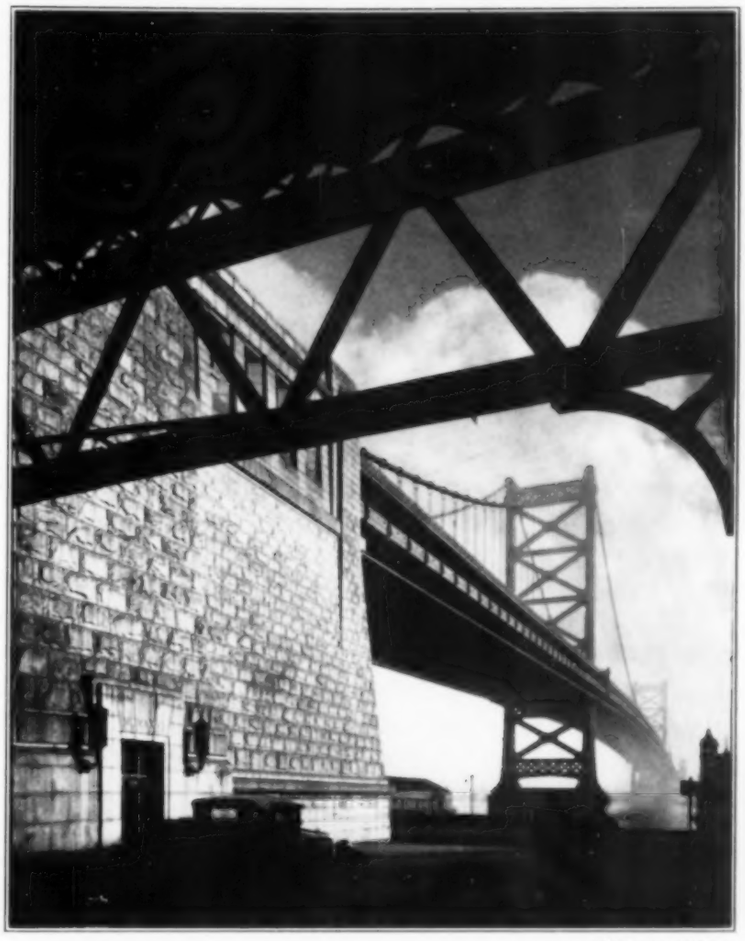


Photo by Rittase

Unexpected Failures

Some qualification is necessary here. During the developmental work on this wire, some 10-ft. lengths were hung over curved blocks on an idle crane girder and a platform on the lower ends loaded with billets, one or two added each day. Unexpected failures at the blocks and at low loads and deficient ductility resulted. (Here we have again a load increasing at a very low rate.) At that time two hypotheses were advanced to explain the tests: (*a*) That the crane girder vibrated and built up harmonic loads, and (*b*) that high stresses existed at the bend and could be relieved by preforming according to the procedure which has been previously described.

To make sure on these points the wire was preformed at the bridge site. As a further precaution, all wire, as it was swaged, spliced, and coiled on the reels for shipment, was passed through a series of closely set, small rolls which bent it back and forth in two planes, somewhat as a piece of sheet is treated in a roller straightener. This was expected to relieve any concentrated internal stress, arising from whatever cause, since every wire drawer knows that a doubtful wire will show a better test on twisting and bending if it is worked in the fingers before it is passed along to the critical examination of the inspector.

Subsequent events proved that these precautions did not change the essential nature of the wire. Final proof of the validity of the hypothesis that the heat treated wire is incapable of withstanding a slowly increasing load is that fractures at low loads and practically zero ductility have been induced in this manner in loops of the Mt. Hope wire in three different laboratories. Five creep testing machines are now in operation at the Bureau of Standards to determine the limiting value of these stresses.

Brittle Under Creeping Loads

It therefore can hardly be doubted that the troostitic structure of quenched and tempered eutectoid steel is unyielding and brittle under creeping loads. Why this should be so is a matter for detailed and scientific investigation. Unfortunately, the fact was not known to the right people, five years ago at the time the material was ordered.

More About Magnetic (?) Superhardening

SCHENECTADY, N. Y. — In the April number of METAL PROGRESS appeared an article by E. G. Herbert concerning the hardening of various alloys by a magnetic treatment. In the June number the writer presented experimental data that was not in accord with that published by Mr. Herbert. In the July and August numbers of METAL PROGRESS Mr. Herbert offers comments upon the work of the writer.

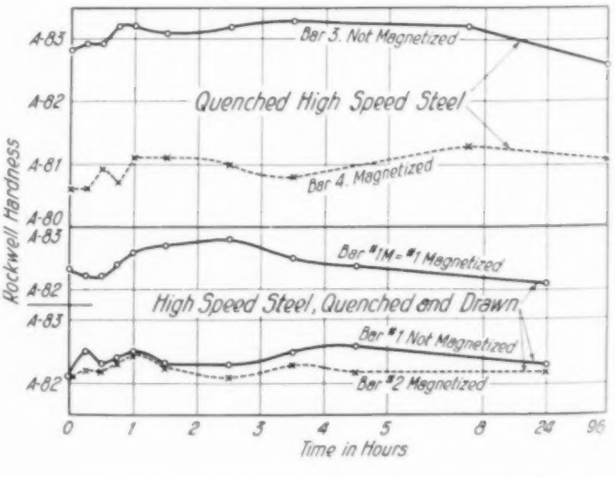
With this additional discussion of "Magnetic Hardening" one might examine the plot of the writer's data on all five bars described in the June issue. Variations of hardness in these bars falls in the range of one-half of one point on the Rockwell A scale. These appear to be of no practical significance, as such fluctuations are characteristic of both the material tested and the method of test. It is also to be especially noted that the bars which did *not* receive the magnetic treatment exhibit variations of the same character and degree as those of the bars which were magnetically treated. To repeat: "The magnetic treatment, as applied to this steel, does not materially harden it."

In Mr. Herbert's July discussion he first claims that only a critical field strength is effective in causing hardening. In his original article he thus describes the electromagnet used in his work: "The electromagnet used has cast iron pole pieces and a fixed gap ⅛ in. wide. The strength of the field within the gap is 6200 gauss." This point is not clear to the writer as Mr. Herbert successfully hardens specimens of various sizes and of different materials. With constant field strength, the magnetic induction passing through the various samples would differ with the size and material of the sample. Mr. Herbert's observations would be more understandable if the flux per sq.cm. were critical for the same material with the same heat treatment.

Secondly, Mr. Herbert found critical flux to be 17,000 c.g.s. lines of force per sq.cm. for a specimen of hard high speed steel 0.071 in. thick. He states that "Too strong a field sets up fluctuations of another character and its effect is quite definitely a softening." In the samples tested by the writer the maximum flux during rotation of a specimen was 21,200 gauss. Therefore a marked softening should perhaps have been observed. No softening is indicated by the data.

Thirdly, Mr. Herbert claims a "body of experimental evidence" against the writer's "two experiments." Actually, the writer presented data from tests on three specimens involving two different heat treatments. Another investigator in the research laboratory of General Electric Co. has conducted an independent investigation and derived the same results as did the writer. No variation was observed after the magnetic treatment. It seems rather more to the point that all of Mr. Herbert's sustaining evidence has had but a single source and that no confirmation from other sources has been published.

Fourth, it is not questioned that Mr. Herbert is measuring real differences in hardness, but that it is solely the magnetic treatment that causes the change *is* questioned. Mr. Herbert states that the hardness variations (after magnetic treatment) as measured by his hardness



Hardness Variations in Heat Treated High Speed Steel, Some Magnetized, Some Not Magnetized Seem to be Within the Accuracy of the Method

pendulum have been confirmed in England by Brinell, Rockwell, Vickers, and scleroscope testers. Are these confirmations from independent investigators from the results of tests on their own prepared and treated samples? If so, have they been published?

Finally, the writer again joins with Dr. Rosenhain in asking that other investigators check this reported action of a magnetic field and publish their results, whether confirming the work of Mr. Herbert, or not.

R. H. HARRINGTON

EAST LANSING, *Mich.* — Superhardening of metals by magnetic exposure has arrested considerable attention recently, and the columns of METAL PROGRESS have contained different opinions from Mr. Herbert in England and Mr. Harrington in America.

For the past seven years the writer has observed superhardening of quenched steels from various causes. Since the results are independent of the method employed, it did not seem that one or another treatment had any peculiar significance.

He regards the phenomenon as being the change of the austenite-martensite structure to complete martensite. This causes the softer austenite to form into harder martensite.

The opinion of Honda and Westgren that alpha martensite is a crystal of the tetragonal system with an axial ratio of 1.06 is questioned. By others alpha martensite is said to be a mixture of austenite and martensite; its crystal might be a pseudomorph (a crystal that may have attained any structure not really characteristic of the material). Be it ever so regular, the deceptive crystal form is under no circumstances a distinctive one. Tetragonal martensite does not seem logical, when the crystal forms from which it is produced and to which it alters are both isometric. The ratio of axes is also observed variously from 1.03 to 1.08. Shift to a different type and variation of the Miller indices are both contrary to good crystallography.

If alpha martensite has austenite in it, and apparently this is true, it will change under the slightest provocation to the more stable form of complete martensite.

Now it is widely recognized that a rotating magnetic field can dissipate heat energy by eddy currents; also that a movement of the atoms or electrons can be effected within the specimen by such a field. The writer therefore presents the opinion that the rotating magnetic field merely starts the transformation of alpha martensite to beta martensite. The heat dissipated by the magnetic field facilitates the transformation by causing greater vibration of the molecules.

Other influences, such as heating the specimen to about 100° C. for a short time, or passing an electric current through it, accomplish the same effect. Typical data follow, which have been duplicated frequently in the past seven years by students at Michigan State College in regular laboratory work. A 1.20% carbon steel is quenched; its hardness is then Rockwell C-63 to C-65. After being exposed to a rotating magnetic field its hardness becomes C-67 to C-68.5. Other specimens of the quenched steel after being dipped in boiling water will have a hardness of C-66.5 to C-67, and these samples subsequently exposed to rotating magnetic field do not harden further (or at most one point).

These oft repeated results indicate that little or no superhardening could be effected by the magnetic treatment after having first placed the steel in the more stable form of beta martensite. This agrees with the results published by Mr. Harrington in the June issue of METAL PROGRESS. It is also to be noted that reheating to 100° C. has about the same hardening effect as the rotating magnetic field.

Water quenched carbon tool steels have also been superhardened on one occasion by passing an electric current through them. The last experiments were done by students in the laboratory, but it is regretted that specific data are not now available.

It is possible therefore to duplicate the results of both Mr. Herbert and Mr. Harrington without any necessary controversy of opinion.

I am at a loss to understand why Mr. Herbert should claim that more sensitive hardness testing would change the results. We have compared the Rockwell hardnesses after superhardening with those obtained with the monotron, which is an exceedingly sensitive instrument at high hardnesses, and we have found the results of both testers to be the same.

The writer would also like to venture the opinion that the severe internal strains which all quenched and cold worked metals contain, might be relieved by slight heat, and, in doing so, start recrystallization, causing greater slip interference and consequently hardening.

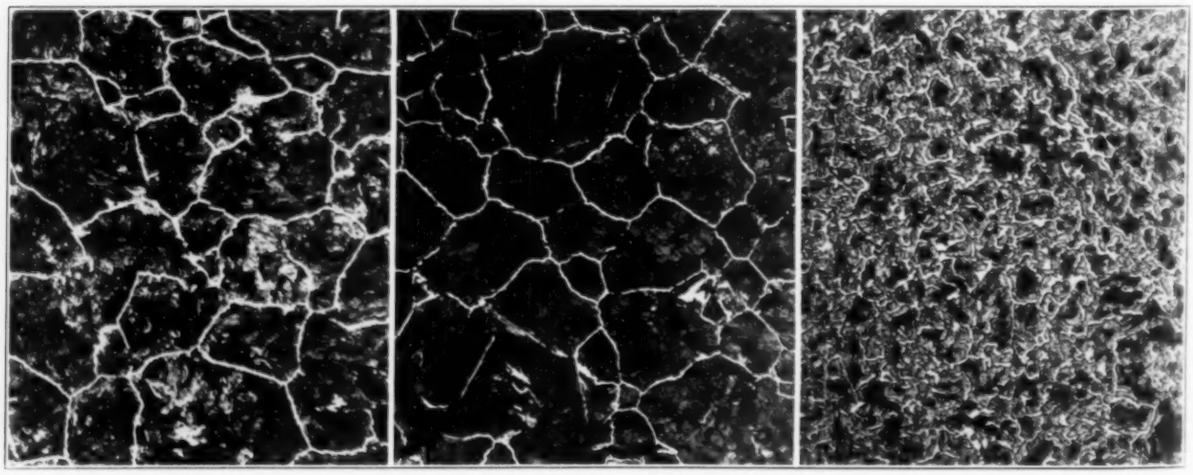
FREDERICK G. SEFING

Carburizing Test for Quality of Welded Joints

DUSSELDORF, *Germany* — As is well known, the McQuaid-Ehn carburizing test shows the difference between normal and abnormal structure of steel. According to Grossmann (METAL PROGRESS, November, 1930) steel which has an abnormal structure contains considerable dissolved oxygen. Duftschmid and Houdremont, however, show in their article published in these pages last May that abnormal structure occurs in the carburized case of synthetic steels free of oxygen, and they think it is a property of pure iron after carburizing.

Whatever the correct theoretical explanation, the carburizing test has been very useful in checking the uniformity of weld metal in a joint. P. Alexander's first tests on this matter are very interesting. He studied the carburized structure of electric welds made in different atmospheres, and found a normal structure after welding in an atmosphere of hydrogen, helium, or carbon monoxide, but an abnormal structure after welding in carbon dioxide or oxygen. It would appear that the quality of the joint is much influenced by the atmosphere surrounding the liquid metal. A more recent development is to cover the electrode with coatings that will simultaneously produce such a protecting atmosphere during transfer of the metal from electrode to the joint, and a slag that will exclude the atmosphere from the molten puddle.

Various tests are in use to check the influence of the different coatings, but the carburizing test gives us a much easier method to get a true picture of the result. If the welding was done with the necessary care and the structure is still abnormal, the composition of the



Structure at 100 Diameters (After Carburizing) of Weld Made With Good Steel and Good Coating, the Steel Plate, and Weld Made With Good Steel and Poor Coating

coating does not give the right protecting atmosphere and must be changed.

Many samples might be shown, cut across a joint and carburized in the standard way. Welds in normal plate may be normal at the root of the V and abnormal at the top. At other times normal veins of metal may occur in abnormal welds. The desired point can be illustrated by the three micros printed herewith. Three small blocks of normal steel were laid side by side, the abutting top edges having first been beveled about half through. One V was then filled with a welding rod having an approved coating; the other with the same steel rod covered with an inferior material.

Both welds were cut through the middle and the central steel block was carburized. After carburizing, the weld made with the good welding rod had a normal structure, the weld with the bad rod an abnormal one. The carburized structure of the plate is also shown. The difference is very remarkable.

It might be noted that a microscope is not necessary to note these large differences in weld structure, as the etched metal is much lighter in color in the abnormal areas.

WERNER ZIELER

Special Nature of Italian Metallurgical Magazines

TURIN, *Italy* — THE peculiar development of the Italian metallurgical industry may explain the situation in which Italian technical publications find themselves. But one must also take into account the fact that foreign languages are more generally known in Italy than in most industrial countries. It is certainly no overstatement to say that every technician (excepting common laborers) can read French, while most foremen and practically all the engineers know enough English or German to understand readily any technical book written in those languages. Since most of the important technical papers and books published originally in English or German are translated into French, it can be said that the whole world's literature is within reach of all of my countrymen who are specialists in industry.

As a consequence, very few technical books are translated into Italian. Publications of native authors are limited to papers or books unique either on account of a new plan or aim of the work, or because the subject itself is quite new. This explains why our technical literature does not include many "standard" books or comprehensive treatises.

Likewise the more limited field of periodical metallurgical literature is strongly influenced by this wide knowledge of languages and the peculiar development of our industry.

At present nine magazines are published in the mining and metallurgical field. Some specialize in mining and consider only those metallurgical subjects connected directly with mining. Others cover special subjects, like foundry operations, and have a purely practical or trade character. Only two of them are devoted exclusively to metallurgy, properly so called, ranging from production of metals and alloys to their technical applications. Most of their contents are devoted to problems connected with the manufacture and treatment of high quality metallurgical products.

The first of the two magazines, called *La Metallurgia Italiana*, is published monthly by the Association of Italian Metallurgists. Of the 100 pages of text forming each number, about one-fourth is devoted to general information (including economic and trade subjects) while 30 to 50 pages contain original technical papers, the rest being occupied by abstracts of foreign technical publications.

In normal times the magazine (which is now in its 24th year) is self-supporting by including 10 to 50 pages of advertising. In the recent hard times the publishing Association has had to meet a small deficit.

The second magazine is published by the same Association, under the title *Alluminio*. It was founded only last year to take care of the papers concerning light metals and alloys which

could no longer find a place in *La Metallurgia Italiana*. A large increase in such literature has followed our rapidly increasing development of aluminum and magnesium. The character, size, and division of contents of both journals are similar.

Considering the widespread knowledge of foreign languages by technical men, and the relatively small number of Italian producers of metals, it might seem a remarkable fact that these magazines (one of which is strictly specialized) should have sufficient circulation to warrant their existence. But their contents meet the unique requirements of Italian metallurgy, and they circulate widely among men in many industries using high grade metallurgical products.

FEDERICO GIOLITTI

Molding Sand With Cement as a Binder

PARIS, *France* — WITH the exception of prehistoric carved stone molds (of which some curious specimens may be seen in museums at Saint-Germain-en-Laye and Zurich) the molding materials used in foundries have always been natural sands — that is to say, materials having both refractory and plastic properties, the refractory part being the silica grains and the plastic binding being the clay containing a suitable proportion of water. While in some exceptional cases magnesia, carbon, zircon, or chromite have been used instead of silica and while an organic binder destroyed at high temperature has been substituted for the clay (such as oil, resin, sugar, cellulose, or rubber) we may say that from time immemorial the binder for molding sands is clay, placed there either by nature or by the foundryman. The cohesion obtained with such materials is insufficient to prevent damage when the mold is moved and manipulated, and for this reason the mold must be externally consolidated by heavy wooden or metallic flasks. This is especially true for molds that must be dried, and cores that are baked.

Widespread use of a new binder, meeting the technical and economic requirements of the foundry industry and, at the same time, offering a greater resistance to casting pressures than the time-honored argillaceous binding, must appear to be a veritable revolution in the art of molding. Yet that is what is now happening in France through the use of an underhydrated cement as a binder for siliceous sands. This process is becoming more widely used and is the subject of M. Maillard's communication to the International Foundry Congress to be held in Paris in September.

A systematic study of the properties of sand and cement mixtures, such as their permeability and their mechanical resistance, allowed him to fix the best conditions for the preparation of the sand heaps, and more particularly of the proportion of water, which is of the greatest importance.

A ratio of water to cement of 1.4 by volume would produce great resistance but no permeability, and consequently such a mixture could not be used for molds. When the ratio is 0.7 to 0.9, good permeability results. The general condition of the molds improves with time and allows the foundryman to make molds with material which originally has the consistence of oily sand, yet, after a time varying from a few hours to one or two days, is strong enough to be manipulated without the support of boxes or flasks.

The compressive strength is at least 75 to 200 lb. per sq.in. and may reach 600 lb. per sq.in.; consequently, it is sufficient to put inside the molds some metal parts so calculated and placed that "reinforced cement" molds are the result. These, being made of an under-hydrated, extra lean mortar, may be poured without drying and with no flasks.

Several thousand tons of cast iron and steel parts in various weights and dimensions up to 15 tons are even now produced annually with this new molding process.

ALBERT PORTEVIN